DES HE SESAR solution 0400 ECO-EVAL

Deliverable ID:	**D5.5**
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:	**07 November 2025**
Edition:	**02.02**
Status:	**Official**
Classification:	**PU**

Abstract

This document contains a qualitative Cost and Benefits Assessment (CBA) for the SESAR Solution 400 (SOL400/SOL2), the Schedule Design Solution. The document is organised as follows: first SOL400/SOL2 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 SOL400/SOL2 will reach TRL2, no quantitative analysis is done.

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Document history

Edition	Date	Status	Organisation author	Justification
01.00 (as D5.5.1)	20.02.2025	Release	MultiModX Consortium	Interim version of the document for review by the SJU
02.00	10/06/2025	Release	MultiModX Consortium	Final version of the document for review by the SJU
02.01	28/07/2025	Release	MultiModX Consortium	Corrected version of the document for review by the SJU
02.02	6/11/2025	Release	MultiModX Consortium	Revised document

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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.

EUROPEAN PARTNERSHIP

Table of contents

EUROPEAN PARTNERSHIP

List of tables

List of figures

1 Executive summary

The Schedule Design Solution (SOL400/SOL2) aims to design passenger-centric coordinated multimodal schedules for air and rail. The passenger-centric aspect comes from the passenger flows calculated using SOL399/SOL1, taking into account the sensitivities of passengers with regard to several travel aspects (mode (air, rail, multimodal), travel time, price and CO_2 emissions) when selecting a specific path, and mode(s), to reach their desired destination. The flows of each path determine the demand to be satisfied by the schedules. The schedules are designed to accommodate the passenger flows as well as possible and, therefore, prioritise coordinating the connections with higher demand.

Using the available data, the Schedule Design Solution generates coordinated air and rail schedules.

SOL400/SOL2 is capable of implementing optimised schedules with the constraints of moving existing services only up to the industries' acceptable thresholds (about 20 minutes in accordance with the Industry Board's feedback). Relaxing these constraints for broader changes will be explored in the experiments.

The objectives when creating the schedules are amongst or a combination of the following:

- minimise waiting times or total travel times for passengers;
- maximise the number of people travelling;
- minimise the deviations from the original schedules;

by accommodating passenger flows as defined from SOL399/SOL1.

The schedule design solution builds upon previous projects from aviation and rail. The approach for timetable synchronisation developed within the SESAR H2020 ER TRANSIT [1] project is extended into a more comprehensive solution to be able to deal with multimodal passenger-centred schedule design at a network level, with the purpose of optimally coordinating air and rail services to minimise the overall passenger journey times and impacts of everyday stochastic disruptions, while taking into account the resources needed by airlines and railway undertakings and the infrastructure capacity. This will benefit from the insights into the airline schedule and strategic passenger flow and schedule generator developed in the SESAR H2020 ER Modus [2] project.

The approaches for optimal railway timetabling from EU FP7 project ON-TIME [3], such as micro-macro models [4], and the integrated passenger-centric multimodal scheduling algorithms from the ERA-NET SORTEDMOBILITY [5] project, like MASP [6], which currently integrate rail and bus services, will be extended towards integrating airline operations

Air and Rail coordinated schedule offer many benefits, 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 of waiting times, reduced travel time, improve diversity of destinations, improve seamless of travel, etc. All of these benefits will improve overall passenger satisfaction over multimodal journeys.

- **Economic benefits**. SOL400/SOL2 presents as well economic benefits, that stem mainly from a more efficient use of the resources (due to schedule optimisation). Most of these benefits will impact the users of the SOL400/SOL2 (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 to replace short haul flights by rail travel, reducing CO2 emissions.

The deployment of SOL400/SOL2 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.

As stated in the OSED, 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 packages.

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). SOL400/SOL2 is aimed at being used by rail operators and airlines wanting to optimise their schedule jointly.

To better evaluate the impacts of SOL400/SOL2, future analysis should examine specific sub-operating environments (e.g., hub sizes, regional archetypes, and connecting itineraries) rather than just the global network and focus on networks with more multimodal and connecting itineraries, such as Spain’s international trips, for deeper insights. This targeted approach would provide a more nuanced understanding of the solution’s effects.

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.

2.2 Scope

SOL400/SOL2 aims at finding optimised 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 types of regions considered in the project), are considered, and only intra Spain trips (i.e. trips that start and finish in 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 SOL400/SOL2 is done using SOL399/SOL1

Multimodal Strategic evaluator, which calculates PIs that can be disaggregated at various levels (sub-operational environments), including the different regions, and even specific origin and destination pairs.

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 SOL-2.

2.5 Structure of the document

The ECO-EVAL presents a preliminary analysis of the economic benefits and costs of the MultiModX SOL400/SOL2. 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 SOL400/SOL2. 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
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*
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*
OD pair	Origin and Destination pair. Refers to the start and end points of each passenger's journey. The number of O&Ds also indicates the size and complexity of a network.	ATPCO Glossary
route-based strategy	Strategy used in the optimisation process, in which a service might be cancelled or added. It can be used jointly with time-based strategy	own elaboration
itinerary	A succession of services (flights or trains) which represent a possible trip for a passenger.	own elaboration
service	A specific train or flight, defined by a succession of stations/airports and its schedule.	own elaboration

EUROPEAN PARTNERSHIP

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

Table: 1 Glossary of terms

2.7 List of acronyms

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

The schedule design solution builds upon previous projects from aviation and rail. The approach for timetable synchronisation developed within the SESAR H2020 ER TRANSIT [1] project will be extended into a more comprehensive solution to be able to deal with multimodal passenger-centred schedule design at a network level, with the purpose of optimally coordinating air and rail services to minimise the overall passenger journey times and impacts of everyday stochastic disruptions, while taking into account the resources needed by airlines and railway undertakings and the infrastructure capacity. This will benefit from the insights into the airline schedule and strategic passenger flow and schedule generator developed in the SESAR H2020 ER Modus [2] project.

The approaches for optimal railway timetabling from EU FP7 project ON-TIME [3], such as micro-macro models [4], and the integrated passenger-centric multimodal scheduling algorithms from the ERA-NET SORTEDMOBILITY [5] project, like MASP [6], which currently integrate rail and bus services, will be extended towards integrating airline operations.

The synchronisation of air and railway timetables has been drawing growing attention recently. Most of the studies focused on the synchronisation at transfer hubs with one airport and one train station. The authors of [7] studied a feeder railway timetabling problem at one transfer hub, in which the flight timetable is given and the feeder railway timetable is optimised to maximise the number of synchronisations and the coverage of synchronised flights and minimise passenger transfer penalties. In [8] a joint design model was proposed that adjusts the given flight and train timetables to increase passenger accessibility at a transfer hub and minimise the time shift of initial timetables. In [9] the authors proposed a demand-driven train timetabling method to minimise passenger waiting time, in which the number of waiting passengers is calculated by the cumulative arrival and service passenger curves. In [10], the authors integrated the rescheduling model of air-rail timetable and passenger flow forecasting to capture the interaction of timetable and passenger flow distribution. In [11], a time-space network-based formulation was proposed for the synchronisation problem of train, aircraft, shuttle and passenger flows.

Very few research studied the air-rail timetable synchronisation problem at a network level. The adjustment of the service timetable at one station not only affects the passengers transferring at the station but also has an impact on other passengers taking the service and other services on the network sharing the same infrastructure. In [12] an optimisation model for air-rail timetable synchronisation to minimise passenger transfer discomfort and schedule deviation was studied. Some network characteristics are considered in the model including the network effect of adjusting the departure time at one station and some operational constraints at stations and airport. The proposed model assumes the transfer demand of each connection is fixed. However, new connections are possible in the synchronised timetable, and passengers may re-choose their itinerary.

The development of SOL400/SOL2 fills in this gap by taking into account demand and building a passenger-centric approach to scheduling by optimising both the air and rail network to account not only for waiting time, but also for capacity whilst also minimising timetable deviation.

3.2 SESAR solution description

SOL400/SOL2 takes the supply (i.e. rail timetable and flight schedules) and demand (i.e. itineraries) characteristics from SOL1 to improve the transfer experience of passengers in the air-rail integrated system by simultaneously coordinating the services and allocating as much demand as possible. The output is the coordinated rail timetables and flight schedules, which can be fed into the strategic evaluator of SOL1 to:

- Calculate the KPIs at the strategic level
- Re-assign the passengers to the coordinated services

SOL400/SOL2 first identifies the demand and services of interest (i.e. transfer demand and corresponding services). Time-based (i.e. timetable shift) are then applied to generate a coordinated schedule of trains and flights. SOL400/SOL2 also identifies the better itineraries in the coordinated schedule and assigns passengers to shift their itineraries.

Multiple objectives are considered in the optimisation model (i.e. unserved demand, transfer time and timetable deviation). Some operational constraints (e.g. running time, dwell time, headway, and airport capacity) and passenger assignment constraints (e.g. minimal connection time and seat capacity) are imposed in the model to guarantee the feasibility of the solution.

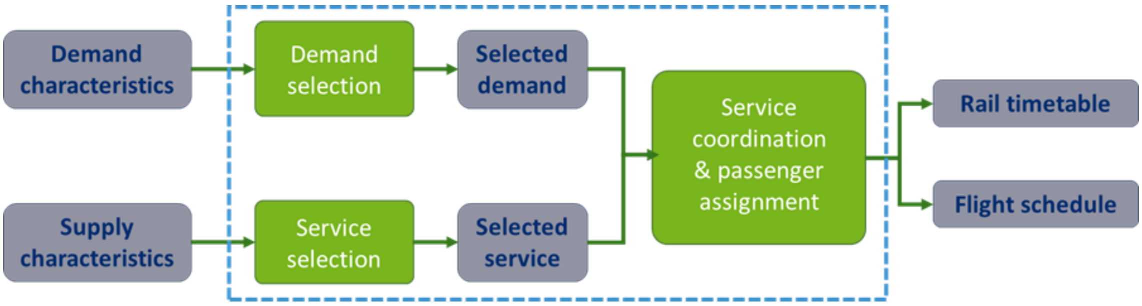

Figure 1: SOL400/SOL2 overview

3.2.1 SESAR solution interdependencies

There are no interdependencies between the Schedule Design 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 Schedule Design Solution 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 the MultiModX Schedule Design 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
e.g. ANSP	e.g. en-route ANS, high complexity ACCs	E.g. invest in new system / new functionality / new tool / training / etc. [Or 'Not applicable']	E.g. improved ATCO productivity / reduced operating costs / etc. [Or 'Not applicable']	e.g. provided inputs, reviewed results, Not involved
Airport operators	N/A	N/A	Increased passenger flow through the airport. Potentially less spending due to more optimal waiting times.	Workers from different airports present in the 1st industry board meeting
Scheduled airlines (mainline and regional)// airline operator	N/A	Invest in new system Training system maintenance Data collection	Increased plane occupancy. Increased sales. Increased customer retention. Reduction of labour and maintenance costs.	Members of airlines present in the 1st Industry Board meeting
railway companies	N/A	Invest in new system Training System maintenance Data collection	Increased train occupancy. Increased sales. Increased customer retention. Reduction of labour and maintenance costs.	Not involved
train stations	N/A	N/A	Increased passenger flow through the stations. Potentially less spending due to more optimal waiting times.	Members of rail networks present in 1st Industry Board meeting
Rail network maintainers	N/A	Increased maintenance costs in some segments	Decreased overall maintenance costs.	Members of rail networks present in 1st Industry Board meeting
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.

IMPORTANT NOTE: 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 synchronise their schedules.

3.5 ECO-EVAL scenarios and assumptions

3.5.1 ECO-EVAL reference scenario

SOL400/SOL2 deployment and implementation is intrinsically linked with the development of Multimodal policies. SOL400/SOL2 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 so called "multimodal policy packages".

Therefore, 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 three policy packages. Different scenarios are constructed based on these policies and other considerations. In this context, the scenarios (reference and solution) include a combination of multimodal policies and a timeline. Scenarios are also based considering network definition, which changes itinerary generation. General information about the scenario definition can be found in table 4.

Category	Sub-Category	Definition
cs (Case study)	cs10: Intra-Spain Mobility	This case study is the main case study of MultiModX. We study the air and rail mobility of the Spanish network but excluding international flights. The analysis of the ECO-EVAL is based on this case study
	cs11: Intra-Spain+International flights	This case study is an extension of the previous one that includes international flights. Although this scenario will not be analysed in the ECO-EVAL, we include it here for completeness
pp (Policy Package)	pp00: Baseline policies	No specific multimodal policies are put into place. This means that multimodal connections are increased with respect to the minimum possible by 30 and 15 additional minutes for rail-to-air and air-to-rail connections, respectively. This asymmetry reflects the potential sensitivity of passengers to missing connections and the inherent uncertainty of the airport and rail station processes when no integrated ticket is present.
	pp10: Multimodality Incentivised	Integrated tickets in place, i.e., rail-to-air and air-to-rail connections, are considered doable as quickly as possible. A CO2 tax for air itineraries is implemented (0.15 EUR / Kg CO2).
	pp20: Multimodality enforced	It is the same as pp10 with an additional flight ban (where a rail alternative under 3h exists).
nd (Network Definition)	nd00: Baseline	max connections in connected itineraries: 2
	nd01: Focus on connecting passengers	max connections in connected itineraries: 2 Connections with mixed operators (air) allowed The focus in passenger assignment is on connecting passengers

	nd02: Focus on total passenger	max connections in connected itineraries: 2 Connections with mixed operators allowed The focus in passenger assignment is on total passengers
so (Schedule Optimisation)	so00.00: Baseline	No schedule optimisation
	s01.01	Timeshift strategies in SOL400/SOL2 Maximum timetable deviation of 20 minutes per service.
	so01.X	This corresponds to X successive applications of SOL400/SOL2 jointly with SOL399/SOL1.

Table: 4. MultiModX scenarios and nomenclature. We note that, as disruptions are not considered, we remove them from this table.

Since we consider three different policy packages, we thus have three reference scenarios. The selected reference scenarios are presented in table 5

Scenario	Definition
cs10.pp00.nd02.so00.00	This is the baseline scenario.
cs10.pp10.nd02.so00.00	Since the policies considered in this scenario are less ambitious than for the pp20 scenario, it has not been considered for the ERR experiments, but it is included here for completeness.
cs10.pp20.nd02.so00.00	This corresponds to the scenario with the most ambitious multimodal policies.

Table: 5 ECO-EVAL reference scenarios

The reference scenarios are also characterised by the network definition. In a nutshell, different network definitions correspond to different ways of generating and populating itineraries from the given air and rail initial timetables. Network definition varies among different Solutions, but for SOL400/SOL2, the network definition that was chosen for the validation of the Solution was nd02, referred as "*focus on total passengers",* where itineraries with a maximum of 2 connections are considered and the passenger assignment is conducted using the strategic evaluator with initial timetables. For more information about network definition, please consult the SOL400/SOL2 ERR.

Finally, the reference scenarios represent the situation without the application of the SESAR Solution. This is labelled as so00.00

Each reference scenario is compared to at least one Solution scenario.

3.5.2 ECO-EVAL solution scenario

__ECO-EVAL timeline__

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

Dates	*<SESAR solution 400>*
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*
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*

Table: 6 ECO-EVAL investment and benefits dates

[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.

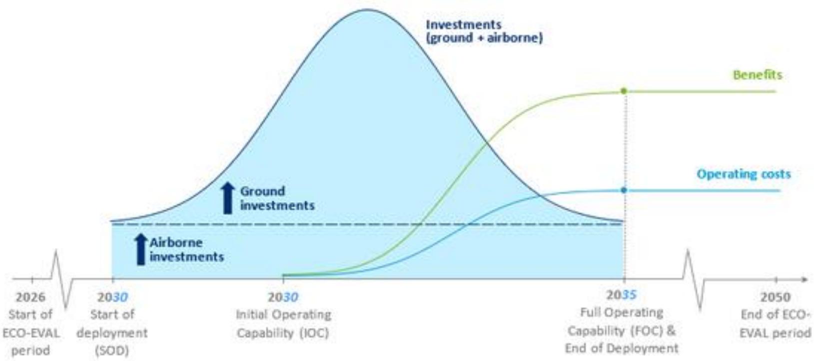

Figure 2: overview of ECO-EVAL dates

The scenarios analysed in the project concerning the validation of SOL400/SOL2 take place in 2030. The deployment of SOL400/SOL2 only requires the download of the code and minimal training to be able to run and interpret the results. Additionally, to get the maximum benefits of the application of SOL400/SOL2, interaction with SOL399/SOL1 is required. No other interaction with any other SESAR Solution is required. We assume that SOL400/SOL2 is applied at country level and that alliances with airlines and railway operators exist (according to assumption A2). The solution scenarios are based on one of the reference scenarios presented in section 3.1.1 and are presented in table 7.

Solution Scenario	Description
cs10.p00.nd02.so10.01	This scenario corresponds to the Spanish air and rail network after one application of SOL400/SOL2.
cs10.p00.nd02.so10.02	This scenario corresponds to a second application of SOL400/SOL2 in the Spanish air and rail network. A second application of SOL400/SOL2 can bring more potential benefits than a single application.
cs10.p20.nd02.so10.01	This scenario corresponds to the Spanish air and rail network after one application of SOL400/SOL2 in a network where Multimodal policies are applied.

Table: 7 Scenario description

The application of SOL400/SOL2 is labelled so10.0x where x is either 1 or 2, corresponds to the number of times SOL400/SOL2 is applied. SOL399/SOL1 and SOL400/SOL2 can work iteratively. Initial itineraries are calculated by SOL399/SOL1, schedules are optimised by SOL400/SOL2, and itineraries with their new demand, load factor and other indicators are re-calculated by SOL399/SOL1. SOL400/SOL2 is a schedule optimiser, and SOL399/SOL1 is capable of showing how passengers will react to the new schedules. Currently, there is one version of SOL400/SOL2, where optimisation is done in lexicographical order using timeshift strategies and a limit of 20 minutes of timetable deviation per service is set.

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 is in place, allowing cooperation between modes of transport (shared data, information, incentive…).	The interest of the project lies 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 as long-distance buses. Coordination with different airlines is also assumed.	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

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 creation of new infrastructure are out of the scope of this project	Low

Table: 8 ECO-EVAL assumptions

4 Benefits

4.1 Benefits overview

The benefits of SOL400/SOL2 according to the SESAR KPIs and PIs are mainly a reduction of direct operating costs, a possible reduction of delays, and a possible reduction of CO2 emissions per passengers. Reduction of operating costs comes from a better utilisation of the network. In the current application of SOL400/SOL2, the number of services and the segments in which these services do not change after optimisation. However, with better schedules, load factors improve, reducing the operating costs per passenger. A reduction of CO2 comes not only from improved load factors, but also from passenger commuting from air to rail and taking multimodal alternatives due to improved service coordination. The application of tools like SOL400/SOL2 can lead to reduced delays since a better coordination of different mode of transportations can reduce air delays caused by delayed 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 SOL400/SOL2 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.

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)
AUC3 Direct operating costs per airspace user	positive impact (ECAC level)	SOL400/SOL2 improves served demand, improving in turn occupancy in certain services. This has a positive effect on directing operating costs, however this effect is low since SOL400/SOL2 only affects connecting itineraries which are the minority of the network.
PUN1 Average departure delays per flight	positive impact (ECAC level)	SOL400/SOL2, by optimising both the air and rail networks, improves the air and rail connections. This can potentially affect departure delays due to commuting passengers not being able to go through all the airport processes on time. This effect is likely to be marginal, but we have decided to include it in this analysis for completeness
ENV1 kg of CO2 per flight	neutral impact (ECAC level)	SOL400/SOL2 will not directly affect the CO2 emissions per flight, but can increase the occupancy of flights and therefore reduce overall emissions per passengers (See Table 10).

Table: 9 SESAR performance framework KPIs and PIs where SOL400/SOL2 can provide benefits

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KPI / PI	BIM impact	How the solution provides the benefit and evaluation (low, medium, high impact)
Kerb to gate time	neutral impact	**Predicted impact:** low. Minimal Kerb to Gate time are assumptions of the model. However, the addition of multimodal policies in scenarios pp10 and pp20 reduce the minimal kerb to gate time.
total journey time	positive impact	**Predicted impact:** High. SOL400/SOL2 is capable of reducing total journey time on average in an entire network. The extend of this impact is directly correlated with the connecting nature of the network. Since total journey times in direct itineraries remains the same after schedule optimisation, the more connecting itineraries, the greater the potential improvement of the network. In validation exercise 1 of the ERR, the total journey time of connecting itineraries went from 417 minutes to 411 minutes. Additionally, in specific itineraries, the decrease was much more important, leading to gains in time of more than 2 hours.
passenger time efficiency	neutral impact	**Predicted impact:** low. Passenger time efficiency measures whether passengers can travel using the "best possible option" or are forced to use slower itineraries. On the one hand, SOL400/SOL2 optimises existing connections, potentially increasing passenger time efficiency. On the other hand, SOL400/SOL2 has the potential to generate new but sub-optimal itineraries between given origin and destinations, decreasing passenger time efficiency but allowing more people to reach their destination.
Buffers in itineraries	positive impact	**Predicted impact:** high. SOL400/SOL2 reduces buffers in itineraries significantly. In some experiments realised in the ERR, buffers were reduced from 20 minutes to 16 minutes on average.
Modal share	positive impact	**Predicted impact:** low. The impact of this metric depends again on the nature of the network. In the experiment realised, the application of SOL400/SOL2 did not have a big impact in mode share, but in certain cases, SOL400/SOL2 has the potential to move passengers from air to multimodal itineraries.

Seamless of travel (time)	negative impact	**Predicted impact:** low. Seamless of time measures transition times between modes and stops. This is an average indicator which is influenced by many factors. In all experiments realised seamless of travel decreased slightly after the application of SOL400/SOL2.
Diversity of destinations	neutral impact	**Predicted impact:** low. Diversity of destinations measures to how many different regions a given region is connected. In the experiments realised for the ERR, diversity of destinations remained stable.
Direct operating costs per user	positive impact	**Predicted impact:** low. Due to higher load factors, direct operating costs can be reduced, but this is not one of the main goals of schedule optimisation. Passenger shifting from rail to air can cause an overall increase in direct operating costs. In most of the experiments, costs remained stable but were slightly reduced in several occasions.
Load factor	positive impact	**Predicted impact:** medium. In all experiments in the ERR, load factor improved (for example, from 67.05% to 69.66%). Demand served is one of the objectives of the optimisation of schedules, so improvement is expected. In some situations, for which demand is higher than seat capacity, load factor might improve only marginally.
Demand served	positive impact	**Predicted impact:** medium. Demand served is one of the objectives of the optimisation of schedules. In most experiments realised, demand served improved after schedule optimisation. However, demand served is also affected by network capacity. An already almost full network has limited potential for demand served improvement
Catchment area of airports	neutral impact	**Predicted impact:** low. In this project, Catchment area is measured as the maximum time it takes to reach said airport. Catchment area can thus decrease if the itineraries to the airport are optimised after the application of SOL400/SOL2. However, catchment area can also increase if a new itinerary is created. Both changes can be considered positive. In the experiments realised catchment area of airports varied.

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CO2 emissions	neutral impact	**Predicted impact:** low. CO2 emission is liked to other indicators such as load factor and mode share. CO2 emissions

Table: 10 KPIs/PIs developed by the project where the SOL400/SOL2 can benefit

Table 9 presents the benefits of the application of SOL400/SOL2 with respect to the PIs developed in the MultiModX project. Note that since SOL400/SOL2 mainly acts on the connected itineraries, the effects are calculated taking into account only connected itineraries, which are only a part of the global network.

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4.3 Direct operating costs per user (AUC3)

SOL400/SOL2 optimises the air and rail network by maximising the served demand, hence potentially increasing the load factor of certain services. This can lead to a decrease in operating costs per user, but this effect is not very significant in the entire network.

scenario	load_factor
cs10.pp00.nd02.so00.00	68.10%
cs10.pp00.nd02.so10.01	68.26%
cs10.pp00.nd02.so10.02	68.27%

Table: 11 load factor for one of the experiments of the ERR

4.4 Average departure delays per flight (PUN1)

SOL400/SOL2 may impact the average departure delays in flights. A better coordination between the rail and the air network may lead to less delays due to delayed passengers coming from the rail network. This impact is likely to not be very significant.

4.5 CO_2 (ENV1)

SOL400/SOL2 does not change anything in all the different phases of plane flight and taxi. However, we acknowledge that a more optimised air and train network might entail the replacement of certain short-haul flights by high-speed rail services. This replacement would not be as a direct consequence of Schedule optimisation, rather as a consequence of shifting demand patterns partly due to said optimisation. This shift can have several potential consequences. In particular, it allows for a better use of the available slots to replace short haul flights by longer flights, less able to be replaced by rail journeys and more CO2 efficient. Therefore, the KPI ENV1 is mentioned here. We propose another related KPI as well in section 4.17. In all the experiments realised, mode share remained more or less stable across the board.

mode	modal share before the application of SOL400/SOL2	modal share after the application of SOL400/SOL2
air	24.18%	24.13%
multimodal	1.47%	1.55%
rail	74.34%	74.32%

Table: 12 mode share in scenarios cs10.pp00.nd02.so00.00 and cs10.pp00.nd02.so10.01

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

4.6 Kerb to Gate time

Minimal Kerb to Gate measures the time it takes to do all the airport processes, i.e., security, boarder control displacements, etc, until a traveller reaches the designated gate. SOL400/SOL2 assumes a Minimal Kerb to Gate time as a modelling assumption, hence in principle, it does not have an impact on this metric. We acknowledge here that in the presence of multimodal policies, the Minimal Kerb to Gate time are reduced as part of the integrating ticketing initiative. This reduces overall Kerb to Gate time before and after optimisation

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. On the entire air and rail network, this effect is not very significant. However, in connecting itineraries, the benefits are significant, are presented in table 13.

scenario	strategic_total_journey_time__avg
cs10.pp00.nd02.so00.00	417.09
cs10.pp00.nd02.so10.01	411.24
cs10.pp00.nd02.so10.02	405.28

Table: 13 Average time on connecting itineraries for different scenarios

4.8 Passenger time efficiency

This indicator comes from the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. It represents the Best possible journey time (from schedules) compared to the planned time travel (from planned operations). SOL400/SOL2 may impact this indicator, but impacts can be both positive or negative. For some Origin and Destination pairs, after schedule optimisation, all existing options can become better, thus improving the number of people that travel using the best or a close to best alternative. For other Origin and Destination pairs, after schedule optimisation more people can travel and new itineraries are created, meaning the percentage of people that travel in a "sub-optimal" itinerary can grow. This effect is offset by the fact that more people are travelling. In all experiments realised, this indicator remained stable on average

scenario	pax_time_efficiency__total
cs10.pp20.nd02.so00.00	87.96%
cs10.pp20.nd02.so10.01	87.98%

Table: 14 passenger time efficiency before and after one application of SOL400/SOL2 in the cs10.pp20.nd02 scenario.

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4.9 Buffers in itineraries

This metric refers to the amount of time used as buffers in connections in itineraries. By optimising connections, buffers in itineraries are significantly reduced.

scenario	buffer_in_itineraries__avg
cs10.pp00.nd02.so00.00	20.39
cs10.pp00.nd02.so10.01	16.39
cs10.pp00.nd02.so10.02	15.71

Table: 15 Buffers in itineraries before and after successive applications of SOL400/SOL2

An example of buffer times reduction after the application of SOL400/SOL2 is presented in table XXX. This represents savings of 65162 minutes over all the passengers using the network.

4.10 Modal share

This metric computes the share of transport modes in passenger itineraries on a specific origin-destination pair. Better optimised networks mean that Multimodal journeys become not only possible, but a more competitive option. However, since SOL400/SOL2 does not change the global composition of the network, the modal share between plane and train is likely to remain roughly the same, (see table 12)

4.11 Seamless of travel (time)

This metric refers to the journey transition time (between modes and stops). Since SOL400/SOL2 aims at synchronising services, we expect a medium impact on this metric. We acknowledge that this time also depends on the layout of the existing infrastructure which is difficult to modify.

4.12 Diversity of destinations

This is the number of destinations which can be reached from a given origin. Since SOL400/SOL2 does not change the network infrastructure, in the experiments realised SOL400/SOL2 did not change this metric. However, in other networks, it might be possible that optimisation of itineraries generates itineraries that connect new regions.

4.13 Direct operating costs per user

This metric is an expansion of the already mentioned (AUC3) PI. In this case it takes into account air and rail. Impacts on this metric can come from different factors. For example, higher load factors in cheaper alternatives tend to decrease operating costs per user. However, due to overall optimisation of schedules, some air alternatives (which tend to be more expensive) might become more competitive

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with respect to rail alternatives, generating a shift from rail to air. This effect can increase the value of this PI. In general, in the experiments realised for the ERR, the operating costs per users remained fairly constant on average, as shown in table 16.

scenario	operating costs per user (euros)
cs10.pp00.nd02.so00.00	54.41
cs10.pp00.nd02.so10.01	54.49
cs10.pp00.nd02.so10.02	54.40

Table: 16 operating costs per user after successive applications of SOL400/SOL2

4.14 Demand Served

This metric measures the amount of people that want to travel and are both able to travel (due to availability of itineraries in the network). One of the objective functions optimised within SOL400/SOL2 is the unserved demand, so we expect its implementation to have a high impact on this metric, especially in connecting itineraries. As expected, the number of people connecting grows after the application of SOL400/SOL2.

scenario	number of connecting passengers	difference
cs10.pp00.nd02.so00.00	18637	-
cs10.pp00.nd02.so10.01	19592	+5.12%
cs10.pp00.nd02.so10.02	20032	+7.49%

Table: 17 number of connecting passengers after successive applications of SOL400/SOL2

Since the ERR results are based in the intra-Spain air and rail network, which is composed primarily of non-connecting itineraries, overall changes in served demand are minimal.

4.15 Catchment area of airports

This metric was proposed in the 'Multimodality and passenger experience in the SESAR Performance Framework' workshop. The catchment area was calculated taking the maximum time it takes to reach the airport via ground mobility (e.g. rail) from which an airport captures demand. SOL400/SOL2 can have different impacts on this indicator:

- The catchment area of an airport can decrease. This could be due to less people accessing this airport after schedule optimisation, but it could also be an effect of itineraries to this airport becoming faster. Hence, a reduction of the catchment area is not necessarily a bad thing for a given airport.

- The catchment area of an airport can increase. This can be due to people coming from further away accessing the facility, but also due to some itineraries becoming worse after schedule optimisation. We remind here that schedule optimisation makes some itineraries become better, at the expense of others becoming worse.

Most airports see no change in their catchment area, so the overall impact of SOL400/SOL2 in this metric is low, but the catchment area of those that changes can vary significantly, (see fig 3)

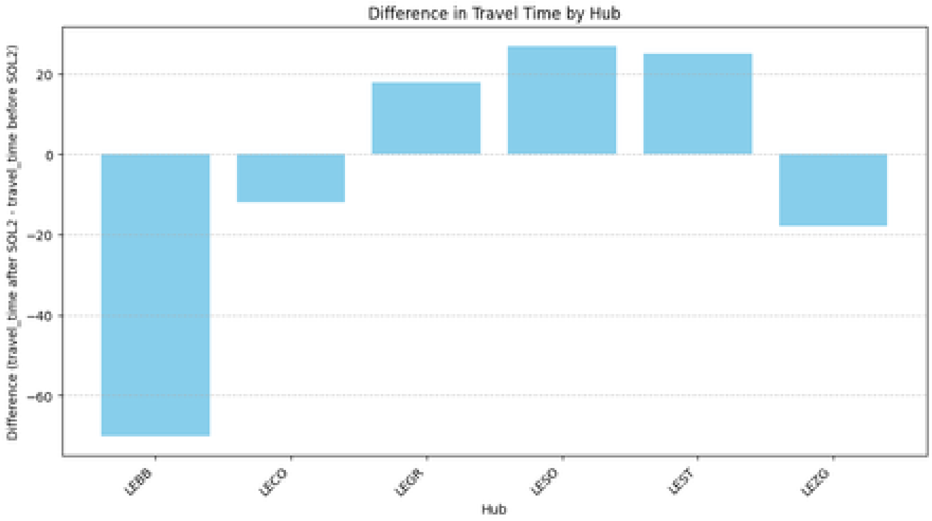

Figure 3: change in catchment area of airports after the application of SOL400/SOL2 in scenario cs10.pp20.nd02.

In conclusion, the impacts over catchment area of airports can be quite varied. In order to have a truly complete picture a case-by-case analysis. A more detailed analysis of the indicator is presented in the ERR document.

4.16 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 the schedule optimisation might have an impact on this metric, namely:

- Increased service occupancy, and a better use of the available rolling stock reduces the CO2 emissions per passenger.
- The potential replacement of some connections from air to rail will reduce the overall CO2 emissions of some trips.

Therefore, the impact of SOL400/SOL2 on this metric is expected to be low on the overall network, especially if most trips taken are direct trips.

5 Cost assessment

Stakeholder	Cost category	Yes/No	Cost driver	Deployment locations (or sub-operating environments)
Airport operators	Investment cost	*No*	-	N/A
	Operating cost	*No*	-	
Scheduled airlines	Investment cost	*Yes*	Invest in new system	N/A
	Operating cost	*Yes*	Labour costs + data collection	
Railway Companies	Investment cost	*Yes*	Invest in new system	N/A
	Operating cost	*Yes*	Labour costs + data collection	
Train stations	Investment cost	*No*	-	N/A
	Operating cost	*No*	-	
Rail network maintainers	Investment cost	*No*	-	N/A
	Operating cost	*NO*	-	
Cities and regional urban planers	Investment cost	*No*	-	N/A
	Operating cost	*No*	-	

Business aviation	Investment cost	*No*	-	N/A
	Operating cost	*No*	-	

Table 10: Cost identification ANSPs costs

IMPORTANT NOTE: 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 synchronise their schedules.

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

SOL400/SOL2 aims to reduce passenger waiting times in Multimodal journeys. This means passengers commuting through an airport might see their connection time reduced to be quite close to the optimal connecting time, reducing their "dwell time" at the airport. This dwell time is particularly important for airport stores, and it is correlated with airport spending (one of the main revenue sources of airports). The reduction of dwell time might thus have a negative economic impact on airports. This is not a cost for airports, but we deemed it worth mentioning due to the potential negative impact it might have.

5.3 Network manager costs

In the current implementation of SOL400/SOL2, the number of services per segment doesn't change. The only costs network managers might face are mainly due to more people accessing some stations/airports (as a consequence of better connectivity).

5.4 Airspace user costs

The implementation and use of SOL400/SOL2 requires minimal costs for airlines that are compensating with reduction of personnel with the optimisation of 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

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

5.7 Scheduled airlines and railway companies

Airlines and railway companies will bear most of the direct costs related with SOL400/SOL2. 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 (SOL400/SOL2 needs data from the network and the demand, i.e. how many people travel from place to place).

5.8 Other relevant stakeholders

N/A

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CBA model

N/A

6 CBA results

N/A

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7 Sensitivity and risk analysis

N/A

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8 Recommendations and next steps

SOL400/SOL2 is, in a nutshell, a schedule optimiser capable of optimising jointly several transportation networks and while taking into account passenger's preferences. Given the results explained in the previous sections, SOL400/SOL2 has the greatest potential of improvement in networks with

- A high proportion of connecting itineraries.
- Airports connected with other modes of ground transportations.

Airports with a co-located train station and with a high catchment area are a good candidate environment for a tool like SL400/SOL2. In this type of environment, SOL400/SOL2 can reduce door-to-door travel time and increase the connectivity of the airport to other regions. Examples of these environments can be airports with "airport express lines", like Rome-Fiumicino, or major hubs like Frankfurt airport and Paris Charles de Gaules.

Additionally, SOL400/SOL2 also has potential in medium-sized airports whose access via public transportation is unideal. SOL400/SOL2. In case of a flight-ban, and especially if rail services in the banned routes are not increased significantly, it is possible that part of the demand that was originally flying directly, diverts to these medium-sized airports instead of taking the rail alternative. Also, if these airports become better connected with ground transportation, they have the potential to relief bigger airports and reduce congestion.

To further refine the concept of SOL400/SOL2, for example in industrial research, the following functionalities could be added:

- Several transportation networks could be included. In order to reach the 4 door-to-door travel hours threshold considered by the Flightpath 2050 initiative, wider coordination among ground and air transportation is needed. SOL400/SOL2 has proven that it is possible to optimise jointly air and train journeys, but for higher TRLevels, this tool could be further developed to include other ground transportation networks, such as buses.
- The optimisation strategies could be expanded. In its current implementation, SOL400/SOL2 changes the departure time of different services (while taking into account industry constraints) but does not change the route of the services. Taking into account that some segments are overserved and underserved, implementing optimisation strategies that include moving resources from one segment to another (while still taking into account industry constraints) should be a priority in the next developments. A proof of concept of this strategy is currently being implemented for the final dissemination event.

9 References

9.1 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] ...

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

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

9.2 Reference documents

[1] TRANSIT

[2] MODUS

[3] CORDIS

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[12] Buire, C., Marzuoli, A., Delahaye, D., Mongeau, M., 2024. Air–rail timetable synchronisation: Improving passenger connections in Europe within and across transportation modes. *Journal of Air Transport Management* 115.

[13] PEARL -- Performance Estimation, Assessment, Reporting and simulation -- Performance Estimation, Assessment, Reporting and simuLation | PEARL Project | Fact Sheet | HORIZON | CORDIS | European Commission

[14] AMPLE3 -- SESAR3 ATM Master Planning and Monitoring – SESAR3 ATM Master Planning and Monitoring | AMPLE3 Project | Fact Sheet | HORIZON | CORDIS | European Commission

[15] SING-AIR -- Implemented Synergies. Data Sharing Contracts and Goals between transport modes and air transportation – https://sign-air.eu/

Appendix A Maturity criteria (self-assessment)

N/A

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