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Abstract

This document outlines the operational service and environment definition (OSED) for the Disruption Management Solution (MultiModX SOL401, TRL2). The disruption management solution aims to provide a framework to determine passenger-centric disruption management measures in multimodal networks. The framework adapts the services of a given multimodal network and provides the correspondingly replanned schedules to minimize the adverse effects on passengers (i.e. number of disconnected passengers, passenger detours and waiting times) w.r.t. service and infrastructure capacities taking into account passengers benefits.

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MultiModX

INTEGRATED PASSENGER-CENTRIC PLANNING OF MULTIMODAL NETWORKS

MultiModX

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1 Executive summary

The Disruption Management Solution (SOL401) aims to design passenger-centric, tactically-adjusted schedules, for air and rail to manage disruptions. Those adjustments are designed to optimally manage passenger demands by minimizing the effects of the disruptions. The Solution takes as input initial passenger flows, including the sensitivities of passengers with regard to several travel aspects (i.e. archetypes), such as travel time or cost, when selecting a specific path and mode(s) to reach their desired destination. The flows of each path determine the demand to satisfy when managing the disruptions. The Disruption Management Solution then adjusts air and rail schedules, the corresponding train routing and flight diversion to accommodate the given demand under disruptions optimally and, therefore, replans 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), along with train rerouting, flight diversions, and rail service replacements on the day of operations. For brevity, we refer to these as adjusted schedules.

In this solution, a Disruption Management Solution will be created, which can manage disruptions at different levels of centralisation: from decentralised disruption management (i.e. cooperation and thus passenger rerouting and service adjustment managed only with respect to the passengers of defined airline alliances) to fully centralised multimodal passenger-centric across all air and rail operators (i.e. full cooperation and thus passenger rerouting and service adjustments between all service providers including airlines and railway undertakings).

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 document outlines the operational service and environment definition of the solution.

2 Introduction

2.1 Purpose of the document

The purpose of this document is to provide a comprehensive definition of the operational service and environment for the SOL401 of MultiModX at TRL2.

This document aims to describe the operational environment in detail, including the operational characteristics, the roles and responsibilities impacted by SOL401, and the applicable standards and regulations. Furthermore, it describes the detailed operating method of SOL401 and its improvements regarding the previous operating method for multimodal, passenger-centred disruption management.

This document serves as a foundational reference for all stakeholders involved in SOL401, including project managers, developers, regulatory bodies, and end-users. By providing a detailed definition of operational service and environment, this document aims to facilitate the successful implementation and operationalization of SOL401.

2.2 Scope

The OSED presents the operational service and environment of the Disruption Management Solution. The overall scope of the OSED covers the definition of the operational characteristics foreseen as part of the WP6 of MultiModX. Further on is the implementation of the methods and algorithms for multimodal disruption management in two versions:

- focus on decentralised solutions, i.e., airline alliances optimise their resources independently when faced with disruption.
- focus on centralised solutions, i.e., the optimisation and decision-making process considers air and rail undertakings, with their capabilities and constraints, jointly.

SOL-3 should be able to reduce the impact of different types of disruptions and disturbances during the day of operation (and/or a day before operation).

These activities address Objective O5 of the project as stated by the Grant Agreement (GA), to develop a Disruption Management Solution based on coordinated passengers' reallocation and tactical replanning of services for air and rail services by:

- Analysing the functional requirements and existing models and algorithms for rail and air disruption management.
- Using mathematical optimisation models and algorithms for optimal multimodal disruption management considering tactical replanning for air and rail, including train routing and diversions, along with passenger multimodal rerouting alternatives. This optimisation will consider passenger behaviour (e.g. acceptable re-routing options), available services and interdependencies between air and rail networks.

- Identifying data-sharing requirements to coordinate the solution due to the distributed nature of the decision-making process when dealing with disruption among stakeholders (e.g. airlines, rail operators, airports, passengers).
- Experimental testing and evaluation of the new Disruption Management Solution.

2.3 Intended readership

The readers of this document would typically include a range of stakeholders involved in the rail and aviation industry, transportation planning, and policy-making. These may include SESAR JU, SESAR IR Projects, SESAR ER projects, EU-Rail, airlines, airports, rail operators, train stations, transportation planners, policymakers, urban planners, researchers and academics, consultants and advisory firms, technology developers, and environmental organisations.

2.4 Background

The disruption management is founded partially on the advanced architecture for optimal and automatic railway traffic management set by the EU FP7 project ON-TIME and enhanced in successive projects such as SORTEDMOBILITY. Those are complemented by the disruption management algorithms developed by the SESAR project TRANSIT and the advanced disruption management mechanisms developed in previous research projects such as CASSIOPEIA II and Domino. The existing disruption management solutions will be extended into a more comprehensive solution able to deal with multimodal passenger-centred disruption management at a network level, to optimally adjust air and rail services to minimise disruption effects on passengers, while taking into account the resources needed by airlines and railway undertakings and the infrastructure capacity. This will benefit from the insight into the traffic management solutions developed in the ON-TIME and SORTEDMOBILITY projects.

The approaches for optimal passenger-centric railway network traffic management, such as railway network vulnerability models [1], and the integrated passenger-centric multimodal rescheduling algorithms from the ERA-NET SORTEDMOBILITY project [2], like MASP [3], which currently integrate rail and bus services, will be extended towards integrating airline operations. Furthermore, approaches to simulate disruption management of the main stakeholders of the ATM environment, explored in the Modus project, will be extended to integrate railway operations.

Apart from the projects cited above, there is very little literature on passenger-centric multimodal disruption management in transport networks with different levels of centralization.

The potential of collaborative decision-making on multimodal disruption management is discussed in ([4]). ([5]) shows the potential of collaborative decision-making and provides recommendations for the multimodal case. Some research covers multimodal real-time disruption management on the local scale, i.e. contingency plans for airport-bound urban transport systems at particular airports ([6], [7]). Other researchers cover multimodal real-time disruption management in national transportation networks by combining air services with flexible ground replacement services, explicitly regarding passengers ([8], [9]). Focusing on operations only, [10] manage national network disruptions in real-time, using existing rail services as replacement. It is noticeable, that the approaches above consider only a limited set of counter measures (i.e. rescheduling, cancellation and vehicle rotation adjustments), but do not incorporate the disruption responsive rescheduling of existing scheduled ground services such as railways. Only [11] introduce a tactical multimodal network approach which adjusts all covered modes in a national network and considers the passenger perspective, using a limited set of countermeasures for each (i.e. rescheduling, cancellation, flight swaps and train short-turning) in a fully centralised manner.

The reviewed literature reveals that recent research does not fully cover the topic of SOL401 as they either focus on disruption management within spatially limited areas (i.e. local or national), unimodal service adjustments, limited sets of disruption measures, have an operational focus or provide only fully centralised approaches for network disruption management. Further, most approaches tackle real-time disruption management problems, whilst only a few cover the tactical perspective with a planning perspective, i.e. dealing with disruptions happening shortly in advance within the day of operations, lasting up to several hours.

The development of SOL401 fills in those gaps by considering multimodal disruption management measures such as schedule, speed and trajectory adjustments in the entire network, allowing rescheduling, cancelling, rerouting and short-turn services. Optimising the aforementioned measures in a passenger-centric fashion for international transportation networks whilst regarding different levels of centralization, SOL401 will contribute to the general research in the multimodal passenger-centric network disruption management field.

2.5 Structure of the document

This document describes the operational and technical characteristics of the Disruption Management Solution (SOL401). First, the detailed operational environment is explained in Section 3, by describing the operational characteristics, the roles and responsibilities involved in the solution and the applicable standards and regulations. Then, the detailed operating method is developed, along with the improvement to the current operating method. The different use cases are described. Finally, in Section 4, the key assumptions under which this solution has been developed are detailed.

2.6 Glossary of terms

Term	Definition	Source of the definition
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.	
Adjusted schedules	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.	
Disruption	Refers to a blocked infrastructure element (e.g. air: airport, terminal, runway; rail: station, track section) or reduced capacity.	

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	More generally, it represents a reduction in the capacity of infrastructure on rail or air network, partial or complete. For rail networks, this comprises a reduction in link throughput and closure of links; for air networks, it refers to reductions in capacity at airports. In the context of SOL401, disruptions are known in advance and impacting significant elements in the system, e.g. several hours (or 1 day) before operations.	
Passenger flow	Refers to an aggregated representation of passengers, travelling along a particular passenger path.	
Passenger itinerary	Passenger itinerary is a succession of services (flights or trains) which represent a (possible) trip for a passenger.	
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	
Infrastructure	For rail networks, rail stations, and systems required to link them (e.g. railways, signalling systems); for aviation, it refers to airports.	

Table 1: glossary of terms

2.7 List of acronyms

Term	Definition
ACC	Air Control Centre
A-CDM	Airport Collaborative Decision Making
ADP	ATFCM Daily Plan
ANM	ATFCM Notification Message
ARC	European Union Agency for Railways
ATC	Air Traffic Control
ATM	Air traffic management
ATFM	Air traffic flow management
ATFCM	Air traffic flow and capacity management
AOC	Airline Operating Centre
AU	Airspace User

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CASA	Computed-Assisted Slot Allocation
CDM	Collaborative Decision Making
CTOT	Calculated Take-Off Time
CNS	Communication navigation surveillance
DBC	Demand Capacity Balancing
DES	Digital European Sky
DM	Disruption management
DMM	Disruption management model
ERA	European Union Agency for Railways
ERP	Exploratory research plan
ETFMS	Enhanced Tactical Flow Management System
FMP	Flow Management Position
GA	Grant agreement
GDS	Global Distribution Systems
GTFS	General Transit Feed Specification
ID	Identifier
MS	Milestone
NM	Network Manager
OECD	Organisation for Economic Co-operation and Development
OSED	Operational service and environment description
SESAR	Single European sky ATM research
SESAR 3 JU	SESAR 3 Joint Undertaking
TAM	Total Airport Management
TRL	Technology Readiness Level
UDPP	User-driven prioritisation process

Table 2: list of acronyms

3 Operational service and environment definition (OSED)

3.1 Disruption Management Solution: a summary

The Disruption Management Solution (SOL401) manages disruptions by adjusting air and rail service arrival and departure times in a coordinated, multimodal, passenger-focused fashion. 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. The model is based on a multimodal network with three layers: infrastructure, services and passengers, as shown in Figure 1. Based on disruptions of the infrastructure, services are adjusted (i.e., rerouted, cancelled, short-turned and retimed). These adjustments are made considering passenger demand (their itineraries), and therefore, the Solution internally considers the possible rerouting of passengers in the multimodal network or if these would be completely cancelled (i. e. cut-off). The used objective function contains different parameters and can be modified to obtain different results. The output of the Disruption Management Solution is the updated flight schedules and rail timetables considering the disruptions and passenger demands.

Figure 2 presents an overview of the Disruption Management Solution (SOL401).

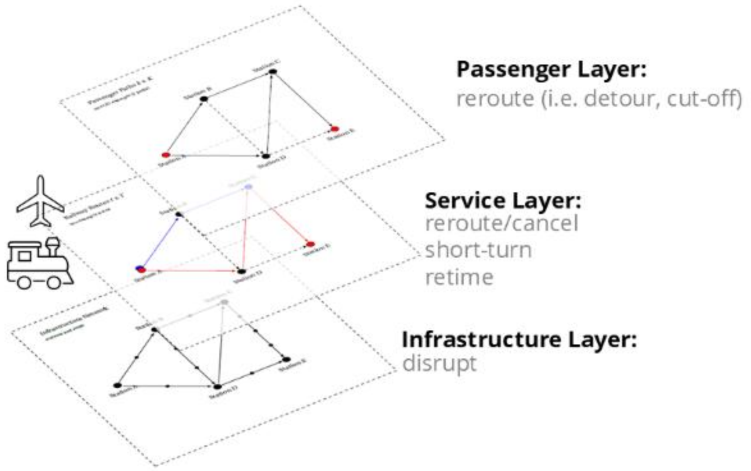

Figure 1: Multimodal network model

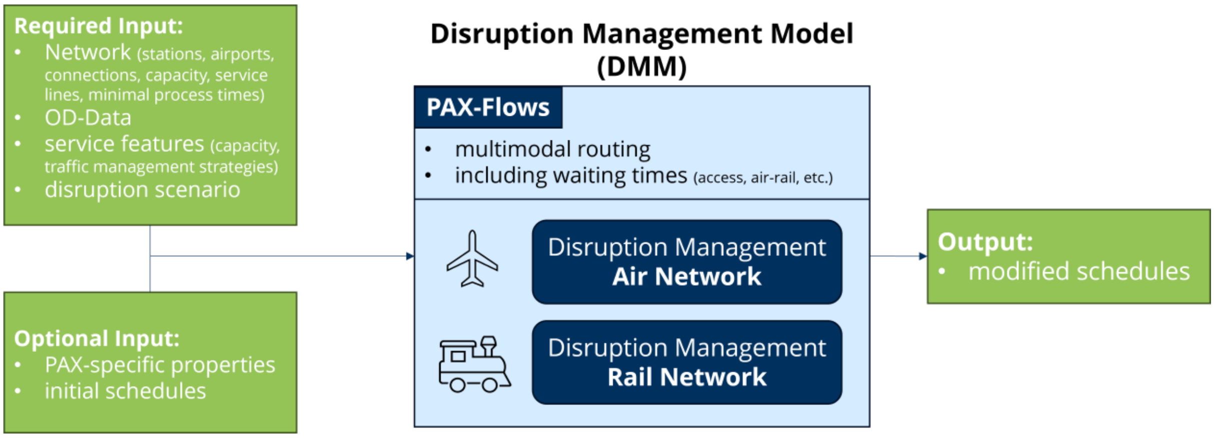

Figure 2: Overview of the Disruption Management Solution (SOL401)

The Disruption Management Solution represents an improvement because it enhances multimodality under disrupted circumstances and offers a better travel experience to passengers even under disruptions. The Solution allows to:

- Provide a holistic consideration of both air and rail system constraints as well as multimodal travelling possibilities, which improve the passenger-centric performance of the system.
- Compute an adjusted multimodal schedule, including adjusted flight schedules and rail timetables, considering given disruptions.
- Evaluate different approaches to replan the operations: decentralised vs centralised, enabling the creation of multiple experiment instances and comparing KPIs.

SESAR solution ID	SESAR solution title	SESAR solution definition	Justification (why the solution matters?)
SOL401	Disruption Management Solution	Replanning of rail and air services considering disruptions in air and rail networks to minimize the potential impact on passenger itineraries.	SOL401 provides better coordination between air and rail services and increases the overall mobility of passengers during known disruptions.

Table 3: ***SOL401*** **scope**

3.1.1 Deviations with respect to the SESAR solution definition

There is no planned deviation from the original solution definition.

3.2 Detailed operational environment

3.2.1 Operational characteristics

The Disruption Management Solution should be used in the tactical and operations planning phase to generate new adjusted schedules, especially in the context of multimodality, when disruptions are expected in air and or rail networks. Hence, it could be applied to generate contingency plans for different disruption scenarios/set-ups or to anticipate known disruptions prior to the day of operations.

Operational environment:

- SOL401 is designed to handle disruptions, which are known well in advance, e.g. several hours before operations, in air and rail networks.
- SOL401 allows for automated decision-making with full integration and coordination between all operators and network controllers (i.e. centralised view) or partial integration presenting current air alliances (i.e. decentralised).
- SOL401 applies to both major hubs and regional airports, ensuring a network-wide approach. The solution shall function independently of airports having an APOC, still capturing any relevant capacity limitations in its disruption management.
- SOL401 supports both frequent small-scale disruptions and large-scale crises, adapting response strategies accordingly. Note that SOL401 does not deal with *nominal* disturbances in the system, i.e., small delays and nominal tactical, operational variances; SOL401 focuses on replanning the schedules when significant drops in capacity are expected in the system.
- By the nature of the activities performed by SOL401 (replanning of operations to support passenger trips), the benefit is expected to be higher for long and mid-distance trips where connectivity and multimodality can provide complementarity and support.
- There are some enablers that should be available in the network for SOL401 to provide its benefits particularly: it is expected that multimodality is available, including the required governance and agreements between operators to ensure that passengers can be accommodated in the network (note that some level of flexibility is possible depending on the approach of the optimisation: decentralised vs centralised.

SESAR-specific operational considerations addressed by SOL401:

- Applicability to both small and large airports: The adjustments are based on available multimodal options while ensuring a network-wide approach. Therefore, even if SOL401 considers (and replans) operations in all SESAR environments (all types of airports), it is expected that benefits (e.g. number of passengers who reach their final destination due to the improvements on the network performed by SOL401) will be more significant at hub nodes where connections (and particularly multimodal connections) are planned (or possible). SOL401 is designed to function independently of airports having an APOC, as it models each airport's capacity and network role individually, accounting for feasible arrivals, departures, and the ability to handle unplanned traffic. While an APOC offers a more structured way to communicate capacity issues to the NMOC, SOL401 still captures and considers any relevant capacity limitations in its disruption management, regardless of an APOC's presence. The solution can be integrated with the Network Manager (NM) and used alongside the CASA algorithm to assign delays and propose replanned operations, factoring in passenger mobility and multimodal alternatives. Airports will continue to report their capacities as they do when issuing ATFM regulations, enabling SOL401 to operate without changes to existing practices or reliance on specific airport configurations. However, future research should consider the impact of redistributing excess traffic to alternative airports and the importance of knowing their capacities independently of ATFM regulations.

- Capacity demand balancing when planned and impacting significant nodes in the network: For the same reason as previously explained, SOL401 is expected to provide higher benefits when dealing with disruptions expected to impact those hub nodes (or links) in the network. For example, when planning for ATFM regulations at D-1, which will significantly (long duration, low capacity) impact operations at a hub, or planned cuts or reduced capacity at critical links in the rail infrastructure.

- Integration with ATM and Network management: Enhances SESAR's Collaborative Decision-Making (CDM) approach by incorporating rail/ground alternatives. SOL401 is expected to be used well in advance of the disruption and to suggest changes in the operations (schedules and timetables) that could then be agreed upon and discussed across the different stakeholders, improving the CDM processes.
- Multimodal data exchange: Requires data exchange between air and rail operators.

As explained in the subsections below, different characteristics of the operations need to be considered to define sub-operating environments in which SOL401 could provide benefits; some of these refer to the characteristics of the operating environment, while others refer to how SOL401 is deployed.

3.2.1.1 Multimodal governance

As stated in Assumption A5, and in line with the SESAR capability of single ticketing, this project assumes that Multimodal governance is in place, including required agreements, data-sharing mechanisms, etc. This is essential for the application of multimodal Disruption Managers such as SOL401. Exactly how this multimodal governance is implemented is out of the scope of this project.

3.2.1.2 Regions

Different regions might benefit differently from the deployment of SOL401 when disruptions are impacting the multimodality network. In this context, European regional archetypes at a NUTS2 level have been identified. Like the EU-Innovation scoreboard, which has classified NUTS2 regions based on the degree of innovativeness, the different European regions are classified based on the degree of applicability of multimodal solutions.

The regions are characterised in different aspects, such as:

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

The analysis identified 3 regional archetypes within Europe:

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

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As mentioned, SOL401 can potentially have a different impact in all these regions. Advanced regions, tend to have more complicated air and rail networks, hence they have a lot of potential for optimisation. However, due to the frequencies of services, these networks might be close to their optimal configuration already and very close to maximum capacity. Emerging rural regions tend to have a simpler network and less services, hence multimodal journeys from these regions tend to be long and cumbersome. SOL401 could thus also bring potential benefits for these regions. A similar situation arises for conservative regions.

3.2.1.3 Infrastructure characteristics

Besides the previously described mobility considerations, different sub-operating environments could be defined by focusing on the infrastructure characteristics, such as the level of connectivity of infrastructure (airports and rail stations) nodes. It is expected that SOL401 might provide more benefits when dealing with disruption impacting these critical nodes (and links) in the infrastructure. Therefore, assessing these independently (e.g. computing indicators focusing on these nodes) could be of interest to stakeholders.

3.2.1.4 Multimodal policy packages

From the current scenario, different reference scenarios can be envisioned as a function of which policies are implemented to support and encourage multimodality. In particular, policies impacting passenger rights, environmental aspects and limitations of aviation. As these policies can be deployed in many different ways, three different policy packages are considered in MultiModX: reference, multimodality incentivised, and multimodality enforced, as shown in Table 4.

Policy Package	Individual policies definition
Reference (no particular policies)	• Passenger rights and multimodality: No integrated tickets • Limitation of aviation: N/A • Environmental regulations: N/A
Multimodality incentivised	• Passenger rights and multimodality: Fully integrated (respecting alliances) • Limitation of aviation: N/A • Environmental regulations: CO_2 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: CO_2 tax applied to emissions

Table 4: Example of possible policy packages

From SOL401 perspective, these policy packages will represent different levels of baseline networks with different levels of multimodality (as computed by SOL1 – Strategic Evaluator). Therefore, the impact of replanning the network when dealing with air and/or rail disruptions could be different in these different reference scenarios. As a function of the level of multimodality, it would make sense to evaluate SOL401 with different levels of centralisation (see Section 3.2.1.6).

3.2.1.5 Disruptions types

SOL401 aims at minimizing the impact of disruptions on passenger journeys. Therefore, the characteristics of these disruptions are critical when assessing the benefits of the Solution. The considered disruptions need to be *large* and known in advance so that the networks can be replanned. To produce meaningful disruptions, a set of disruptions are grouped into *disruption packages*, as illustrated in Table 5. These distribution packages consider things such as rail corridor closure and/or reduced capacity and ATFM regulations applied at hub airports. These disruptions can occur in one network (air or rail) or simultaneously in both.

Disruptions with its parameters may lead to different scales of impact on SOL401 outcomes (delays and/or cancellations and/or diversions).

SOL401 is working with disruptions known in advance so that there is enough time to implement the replanning of operations. How much in advance would depend on the amount of changes required to the network, the flexibility of the operators to implement these and the possibility for passengers to be notified of their potential alternative itineraries. Based on Validation exercise #2 in ERR and feewdback of stakeholders, we decided to consider 1 day ahead of operations.

SOL401 could work in real-time, however, time to implement certain decisions like passenger rerouting may be prohibitively small in todays operations.

SOL401 could support even more critical type of disruptions, such as (multiple) link or infrastructure closures. In that case, if known in advance SOL401 will work fine, if sudden, SOL401 could provide a plan of action on how to replan the network.

For small variations of the operations in the system, e.g. delays or even sporadic cancellations, a replanning of the whole network is not desirable, and in that case instead of SOL401, mechanisms to support multimodality could be deployed at airports as validated by the Tactical Multimodal Evaluator of SOL40199/SOL1.

Disruption package	Disruptions definition	Levels
No disruption	• No disruption modelled	• N/A
Air network disrupted	• Significant disruption in airport capacities	• Based on historical ATFM regulations at hub airport(s), which generated high delays.
Rail network disrupted	• Significant disruption in rail links capacities	• Based on the most important links in the rail network.
Air&Rail network disrupted	• Significant disruption at both networks	• Air and rail at the same time.

Table 5: Example of possible disruptions packages

3.2.1.6 Level of centralisation

As previously explained, SOL401 provides 2 levels of centralisation between air and rail operators: **centralised**, i.e. all involved operators fully commit to coordination during disruptions allowing synchronising multimodal services between all air and rail operators without limitation, and passengers can freely be reassigned between all, and **decentralised**, i.e. coordination exists only within existing airline alliances on one side and rail operators on the other, passengers are reassigned within the respective alliances.

The former may assume the existence of a new "multimodal" network operator, while the latter - air/rail network operators.

3.2.1.7 Summary of operational environment characteristics

As presented, there are different aspects that can be considered for the definition of the operational and sub-operating environments. The characteristics presented in this document will be used to create the experiments (solution scenarios) in the ERP [12] and to analyse the results, i.e., focusing on disruption occurrence in air or rail networks and capturing the impact of multimodality in those environments.

The operational environments will, therefore, be a combination of regional archetypes, policy packages, levels of centralisation, and disruption packages for the assessment of the impact of disruptions on the planned networks, and the results could be assessed at the network level but also focusing on different infrastructure nodes.

The experiments defined in the ERP [12] will ensure that the different characteristics of the sub-operational environments are captured.

3.2.2 Roles and responsibilities

The components developed in SOL401/SOL401 could be integrated within the SESAR architecture. Some of the roles involved would be:

- Network Manager: In charge of assigning delays when regulations are issued in the air network. In the case of SOL401, the Network Manager would use the disruption management framework to minimise the impact of disruptions on planned operations and the respectively resulting multimodal network capacities. The Network Manager would then share the information (replanned network) with other relevant stakeholders to assess collaboratively if their operations are replanned as indicated by SOL401. The Network Manager would, as part of the collaborative process, assess if the regulations are still needed and, if so, implement them accordingly. Note that this role could be split between an air Network Manager (as currently in the SESAR architecture) and a Multimodal Network Manager, which would deal with the air and rail interactions and with the optimisation of both networks. In that case the Multimodal Network Manager would be the one executing SOL401, including gathering the required information, and providing the outcome to the other relevant stakeholders.
- Airline Operating Centre: the AOC could use the disruption management framework to design multimodal contingency plans to encounter disruptions during the tactical planning stage. In the case of potential future alliance-wide, coordinated traffic management, the framework can also be used to coordinate capacity allocation among the associated airlines. Besides this

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independent usage of SOL401, as part of a collaborative process to manage disruptions, the AOC will be provided with the replanned operations (schedules) and will engage with the NM to replan their operations accordingly. The AOCs need to provide/share also information on the passenger itineraries (demand).

- Flow management position: the FMPs of the ACC provide the NM with the planned regulations. (For details, please see Sections 3.3.1.1. and 3.3.2.1.)
- Rail Operator: The rail operator, as the AOC, will engage with the NM on the replanning of their operations if SOL401 provides updated timetables that should be used to deal with the planned disruptions. The rail operators need to provide/share also information on the passenger itineraries (demand).
- Rail Infrastructure Manager: The rail infrastructure manager provides the NM with the planned/expected disruptions in the rail network.
- DM Performance Assessment expert: could use SOL401 to assess how the network could be replanned to deal with disruptions under different assumptions. SOL401 would, therefore, be used as a 'what-if' evaluator, which could provide operational plans for different operational situations. These DM Performance Assessment experts are therefore an abstract role which could be instantiated by different other actors, such as infrastructure managers, to assess how changes in the operation of their infrastructure could impact passenger experience (delays and missed connections); airlines and rail operators could assess how replanning their network can support passengers in case of disruptions.

3.2.3 CNS/ATS description

SOL401/SOL401 does not have any impact on the CNS/ATS as it does not modify the tactical operation of flights. The existence of Multimodal Governance and coordination between air and rail would encourage the use of the Solution.

3.2.4 Applicable standards and regulations

SOL401/SOL401 does not require and would not impact standards and regulations, as it is a standalone decision-making tool. There are assumptions about regulations being in place when assessing multimodality (e.g. the existence of multimodal governance) but not on how to use the models and framework developed within SOL401.

There are existing tools to generate separately disruption management for air and rail, however, the SOL401 is able to optimise the entire network of air and train as a whole, by considering an air layer and a train layer and taking into account the passengers demand explicitly.

3.3 Detailed operating method

3.3.1 Previous operating method

For the previous operating method, we differentiate between how disruptions are managed in the air (Section 3.3.1.1.) and rail networks (Section 3.3.1.2) and describe the existing collaboration (Section 3.3.1.3).

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3.3.1.1 Air network previous operating method

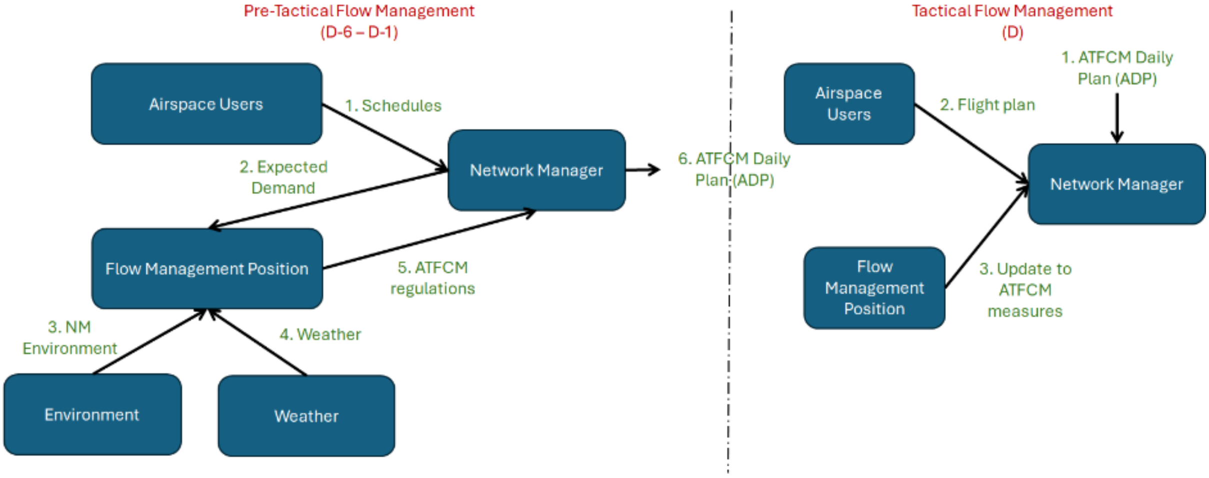

Figure 3: Previous operating method – air network management.

SOL401 will provide capabilities to manage disruptions in the air and rail network in the Pre-Tactical and Tactical phases. Therefore, it focuses on the planning of the operations to deal with these disruptions in both the Pre-Tactical and Tactical Flow Management phases. SOL401 will modify how the planning activities to deal with disruptions are handled. Therefore, a high-level simplified view of the operating method used without SOL401 is described here based on the Network Operations Handbook – ATFCM operating procedures for flow management position [13].

Figure 3 presents a high-level simplified view of the main activities and data used in the Pre-Tactical and the Tactical Flow Management phases. Pre-Tactical Flow Management is applied during the six days prior to the day of operation and consists of planning and coordination activities [13]. This phase analyses and decides on the best way to manage the available capacity resources and on the need for the implementation of a wide range of appropriate ATFCM measures. The output is the ATFCM Daily Plan (ADP) published via ATFCM Notification Message (ANM) / Network News and via the NOP portal [14].

As shown, the Flow Management Positions will use information on the Environment, Weather and other aspects that could impact the capacity of their ACC along with forecast on demand to define the ATFCM initiatives to be implemented on the day of operations (D). The NM will coordinate and define the daily plan and inform aircraft operators and ATC units about the ATFCM measures. Through the ATFCM Daily Plan the NM is trying to optimise available capacity to meet forecast demand and to manage demand to minimise delay and cost. The NM shall publish the agreed plan for the day of operations after a collaborative decision-making process [14].

The outcome of the Pre-Tactical Flow Management phase will, therefore, be the published ATFCM Daily Plan with the set of ATFCM measures that will be in force in European airspace on the following day [13].

On the day of operations, airspace users will submit their flight plan to the NM, who will assess if they are impacted by any ATFCM measure. If so, flights will be assigned to slots, and CTOT will be issued as part of the ETFMS using the CASA algorithm. The initial assignment of slots is performed with a focus on respecting the declared capacities of the implemented regulations while minimizing the total assigned delay. There is no consideration of the impact of delays on passengers, who can experience significantly larger delays due to missed connections (this is particularly relevant in the context of multimodality). UDPP Solution enables air operators to exchange some of the slots so that their expected costs can be reduced partially. However, this approach still provides some limited improvement for passengers as the overall vision of the impact on their journeys is not considered. And, most importantly, multimodal journeys and how the rail and air network could support and complement each other in case of disruptions in the infrastructure are completely ignored.

There are many dynamic aspects of the tactical management of the slots, e.g. cancellation, ready messages, and flight plan alternatives; these are, however, out of the scope of SOL401, as there is no plan to modify this in the Solution operating method (see Section 3.3.2 New SESAR operating method for more detail). For more information on the tactical dynamic management and assignment of slots, the reader is referred to [14].

Finally, as depicted in Figure 3, the ADP can be modified if necessary through real-time optimisation of capacity/demand, e.g. by modifying the aspects of ATFCM initiatives such as duration or rate of the ATFM regulations.

Besides these network activities to manage demand and capacity imbalances, airspace users (and other stakeholders, e.g. ground handlers) can manage their resources to mitigate the impact of these disruptions. These actions are overall distributed and focus on minimizing the impact on the individual operations of the different stakeholders. For example, under disruptions, airlines often aim to rebuild their planned operations, e.g. flight swaps and cancellations, and to accommodate passengers to avoid compensation costs. Information exchanges can be limited, and the degree of cooperation strongly depends on the situation, the available information and the competitive context (i.e., the presence of alliances).

In order to mitigate the reactionary impact of disruptions on operations, different approaches can be implemented. For example, Airport Collaborative Decision-Making (A-CDM) is based on the principle that relevant stakeholders involved in airport operations—airlines, air traffic control, ground handlers, and the airport operator—should share information and work together to make decisions [15]. This collaborative approach ensures that decisions are based on a comprehensive understanding of the current situation, leading to more efficient and effective outcomes during disruptions. Key elements of CDM are information, joint decision-making, pre-agreed procedures, real-time monitoring and adjustment and predictive analytics. SOL401 aims to bring some of these collaborations to the pre-tactical phase.

Total Airport Management (TAM) expands on the principles of CDM by taking a holistic, system-wide approach to airport operations. TAM aims to optimize the performance of the entire airport by integrating all components into a unified management framework. In the context of disruption management, TAM focuses on improving overall airport resilience through comprehensive coordination and resource management. TAM include key aspects of centralised control, integrated systems, resource optimization, scenario-based planning and stakeholder collaboration [16].

3.3.1.2 Rail network previous operating method

On the rail side, a network controller (infrastructure manager) receives information about the disruption and designs mitigation dispatching strategies, including train rerouting, cancelling, short-turning and retiming. In case of larger disruptions, these can include (manual) coordination of multiple control centres in the network. In an exchange with the network controllers, the corresponding railway operators dispatch their staff and rolling stock. The strategies are applied mainly from the service perspective, not necessarily considering passenger flows and routing explicitly. Passengers are guided only by information systems and reassign themselves to new services.

3.3.1.3 Coordinated network previous operating method

Currently, there is no coordination between air and rail operators in the context of disruption management.

3.3.2 New SESAR operating method

3.3.2.1 Overall new operating method

SOL401 focuses on providing support to manage disruptions during the Pre-Tactical Flow Management phase. As will be shown, in some cases, it can also provide support during the Tactical Flow Management phase with real-time updates.

For air transport, applying Multimodal DM SOL401 one day ahead is compatible with the definition of the ATFCM Daily plan but also, if time allows it, it could be run on the day of operations to account for updates to the ATFCM plan and the dynamicity of the disruption in real time. Selecting the horizon of 1 day ahead of operations is an outcome of the Validation exercises.

SOL401 could work in real-time, however, time to implement certain decisions like passenger rerouting may be prohibitively small in todays operations.

SOL401 could support even more critical type of disruptions, such as (multiple) link or infrastructure closures. In that case, if known in advance SOL401 will work fine, if sudden, SOL401 could provide a plan of action on how to replan the network.

Overall, the Disruption Management Solution takes into account demand flows in the network with restrictions on seating and service capacity in the context of disruptions. Disruptions are events, whose (expected) effects are large (i.e. affecting multiple services and/or network parts), which are not caused by regular, stochastic events, and whose duration exceeds the magnitude of typically scheduled buffer times and is thus likely to require major replanning activities. We particularly consider disruptions that occur several hours in advance. This provides enough time for services to be replanned and passengers rerouted. It could be possible to execute the Disruption Management Solution with a shorter look-ahead time but some constraints on what changes are allowed might be required to ensure the deployability of the updated replanned network. Examples of the disruptions considered are the closure of a rail track or a station, e.g. due to an immediate need to repair, an airport or flight corridor(s) due to expected adverse weather.

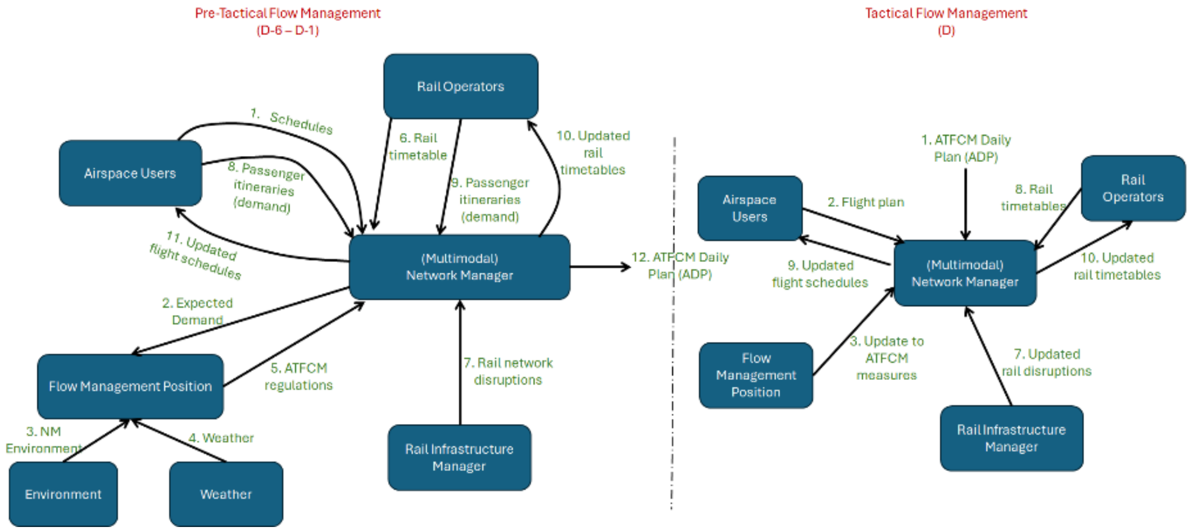

Figure 4: New operating method SOL401

As depicted in Figure 4, the current operating method (see Figure 3) is extended to include the rail network and the passenger itineraries, supporting the development of a Multimodal Network Manager.

During the Pre-Tactical Flow Management phase, the (Multimodal) Network Manager would receive the schedules of Airspace Users (depicted as interaction/arrow 1 in Figure 4 (Pre-Tactical Flow Management side)) and information on ATFCM regulations and initiatives suggested by the Flow Management Positions (depicted as 5 in Figure 4). These ATFCM regulations are defined based on the environment (3), weather (4) and expected demand (2)). These processes will be as in the Previous Operating Method (see Section 3.3.1.1).

In addition to this information, the Network Manager would receive information on the rail timetables from the Rail Operators (depicted as 6 in the Pre-Tactical Flow Management part of Figure 4), and on any expected rail disruption from the Rail Infrastructure Manager (depicted as 7 in the Pre-Tactical Flow Management part of Figure 4). The Rail Operators and Airspace Users will also provide information on their passenger itineraries (mono and multi-mode itineraries (8 and 9 in Figure 4)).

With all this information, the Network Manager would execute the Disruption Management Solution (see Section 3.3.2.2), obtaining updated flight schedules and rail timetables which will respect the infrastructure capacities (ATFCM regulations and Rail Infrastructure restrictions) and, potentially, minimize the impact on passenger itineraries.

These updated flight schedules and rail timetables would be shared with the Airspace Users and Rail Operators, respectively (10 and 11 in Figure 4), who will consider them to replan their passenger itineraries, allowing them to notify and manage passengers even before their journey starts (e.g. re-routing passengers in the newly generated network). The consideration of passenger itineraries (including their multimodal and rail journeys) and the status and capabilities of the rail network when replanning the operations by the Disruption Management Solution transform the Network Manager into a Network Manager with Multimodal capabilities. This transition could be deployed in stages, e.g. first considering only replanning air operations but no rail operations, or considering only air and multimodal passengers but not the replanning of rail itineraries themselves.

Note that as demand has been modified, some of the regulatory actions (ATFCM initiatives) might no longer be needed. This could trigger a CDM process of negotiation between the AUs, FMP and NM to adjust (as needed) the ATFCM initiatives to create the final ATFCM Daily Plan (ADP). Additionally, the updated rail timetable would be shared with the Rail Infrastructure Managers (RIM) to adjust the existing train paths and/or allocate new paths for scheduled replacement services. Some additional synchronisation between RIM and ROC could be expected.

On the day of operations, the ADP will be deployed, and slots (and delays) will be assigned by the Network Manager to flights according to the flight plan received as in the Previous Operating Method (see Section 3.3.1.1). As depicted in Figure 4 (Tactical Flow Management (D) side), the ADP will be provided to the Network Manager (depicted as 1 in Figure 4), the NM will receive the flight plan from the AUs (depicted as 2 in Figure 4) and provide ATFM slots as needed (as in current operations). The Flow Management Positions, also as in current operations might update the ATFCM measures (depicted as 3 in Figure 4).

It is expected that if flight schedules are optimised as suggested by SOL401, then the total delay required would be lower than otherwise. Finally, as in the Previous Operating Method, the FMPs would update their ATFCM measures as needed during the day of operations (depicted as 3 in Figure 4). Similarly, the Rail Infrastructure Manager could update their rail network disruptions (depicted as 7 in Figure 4), and the Rail Operators could provide updates on the status of their services (depicted as 8 in Figure 4).

If time allows, one could envision that if a significant change to the ADP is produced, e.g. a significant real-time disruption update, the NM could re-optimise the remaining of the day with SOL401 providing updated schedules for flights and rails (depicted as 9 and 10 in Figure 4). This would be possible if the updated disruptions are known with sufficient lookahead time so that the replanned network can be implemented and passengers are adequately notified of any changes to their itineraries.

As such, SOL401 is designed to support multimodal disruption management. However, the solution can either support or partially replace ATM disruption management, but also can be applied other modes' disruption management systems individually in a modular fashion. If SOL401 is used on the day of operation to update the ADP and assign delays to flights, then an integration with the current capabilities of the Network Manager would be required. Finally, it is worth noticing how the capabilities of SOL401 allow their use even during the day of operations as a what-if evaluator. SOL401 would then provide suggestions on how to manage the demand with the available capacity minimizing the impact on passenger itineraries. As such, it could be a complementary service to the iNM, which could also support operations in case of crisis management (e.g. suggesting how to replan operations in the event of large capacity reductions).

3.3.2.2 Disruption Management Solution operating method

The Network Manager is expected to provide to the Disruption Management Solution information on:

- supply, consisting of:
    - rail timetable in the standard GTFS format,
    - flight schedules
    - list of alliances between operators (air and/or rail)
    - specifications of operating vehicles, i. e. number of seats,

- infrastructure, consisting of:
    - airports and/or rail stations and the corresponding feature,s i. e. capacity, minimal process times, etc.
    - possible connections/corridors between the airports/stations and the corresponding features, i. e. capacity, minimal process times, etc.
    - minimum connecting times (MCT) intra- and inter-mobility layers, i.e., the time required to travel from rail stations to airports (and vice-versa) and to connect between flights (at airports) and between trains (at rail stations)
- demand, consisting of:
    - number of passengers between stations(origin-destination demand) per passenger category (i.e. first/business class, second/economy class). These can be in the form of passenger itineraries.
- disruption characteristics, consisting of:
    - affected network elements (e.g. one or more links and/or nodes)
    - effects of the disruption per network element (i. e. magnitude of capacity reduction)
    - duration of the disruption
- disruption management preferences, consisting of:
    - maximum detour parameter per service
    - focus parameter to manage traffic with a focus on avoiding passenger detours vs. OD disconnections
    - railway short-turning facilities, i. e. stations, where services can terminate
    - operating cost factor [€/min] per service
    - passenger loss cost factor [€/PAX] per archetype

The Disruption Management Solution generates adjusted, passenger-centric schedules in the context of multimodality under disruptions. The primary goal is to offer a seamless experience to the passengers by:

- reducing the number of stranded passengers (i. e. cancellations);
- reducing the passenger delays;
- offering new connections, improving accessibility under disruptions;
- providing sufficient capacities for feasible service operations;
- etc.

The Disruption Management Solution adjusts services such that the number of stranded passengers and the passenger delays are minimized w.r.t. the original services and schedule. Correspondingly, the affected services are rescheduled with regard to possible rerouting or short-turning options. Additionally, replacement (air or rail) services are planned to provide transport for the disrupted demand flows.

The passengers are rerouted within the network of the corresponding airline alliance (i.e. representing a decentralised approach). If no alliances are given, all available services are considered for rerouting (i.e. representing a centralised approach). Consequently, depending on the provided alliances/cooperations, the solution allows the provision of optimal replanning decisions for centralised (w.r.t. all services and available passenger connections) or decentralised (only optimal decisions within the considered airline alliances) set-ups.

The following figures illustrate the disruption management measures and the corresponding effects on passenger routing. The original services and passenger assignments are depicted in Figure 5.

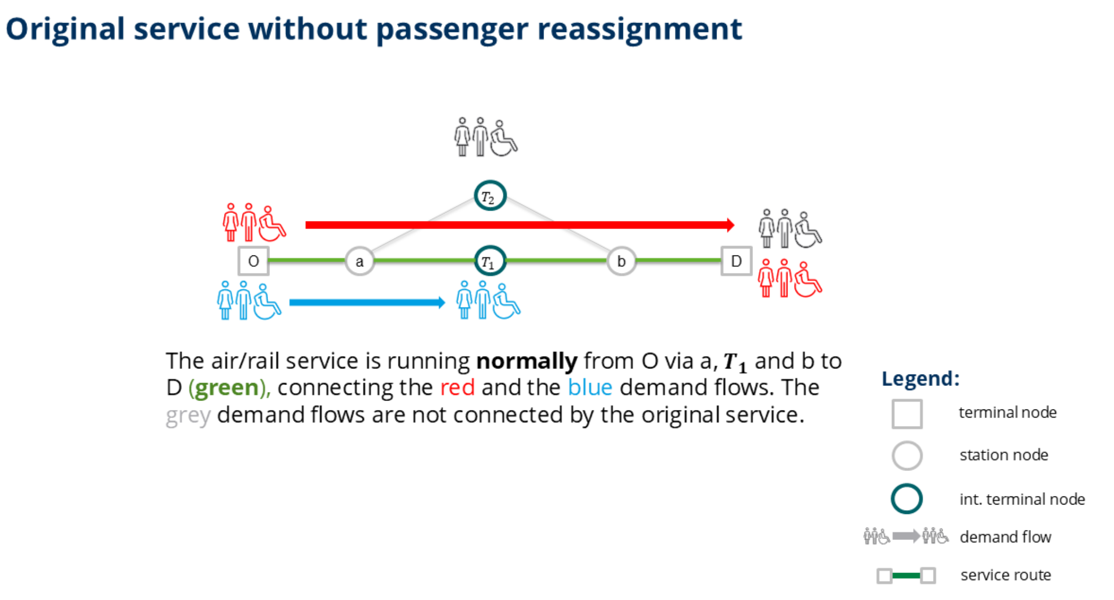

Figure 5: Original services (highlighted network edgers) and passenger demand flows (colored arrows)

In case of a disruption, the services are adjusted. The overall goal is to minimize the number of stranded passengers, which results in short-turning to provide services to the maximum number of travellers if possible, which is shown in Figure 6.

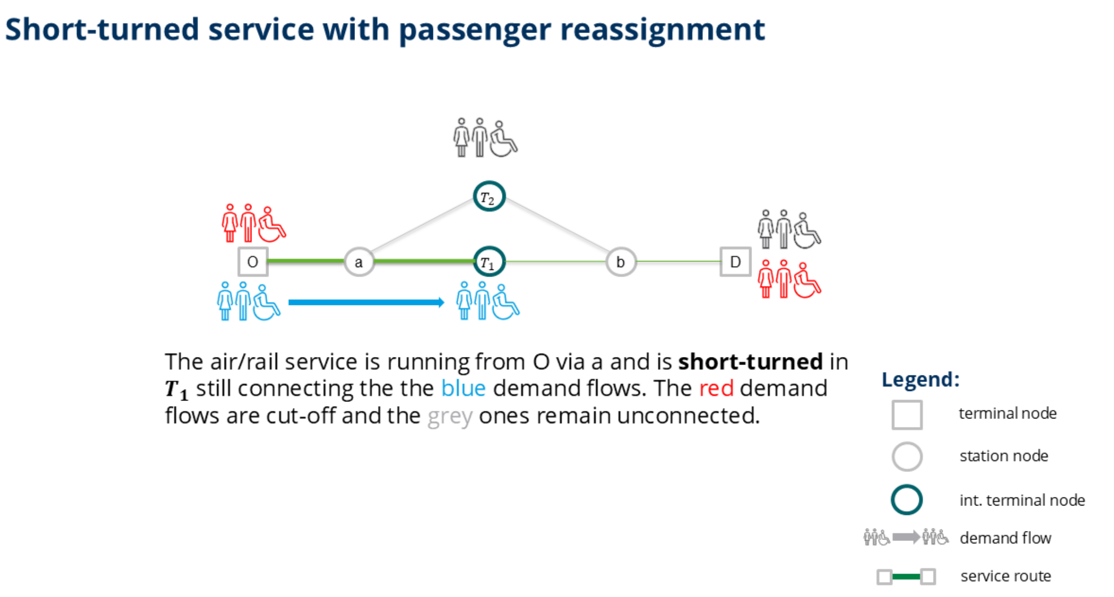

Figure 6: Short-turning of services

To minimize passenger delays, the rerouting is managed w. r. t. shortest-path principles. Depending on the selected routes and the available demand, also additional connections can be provided. Others might be disconnected. An example of rerouting services and passenger reassignment is shown in Figure 7.

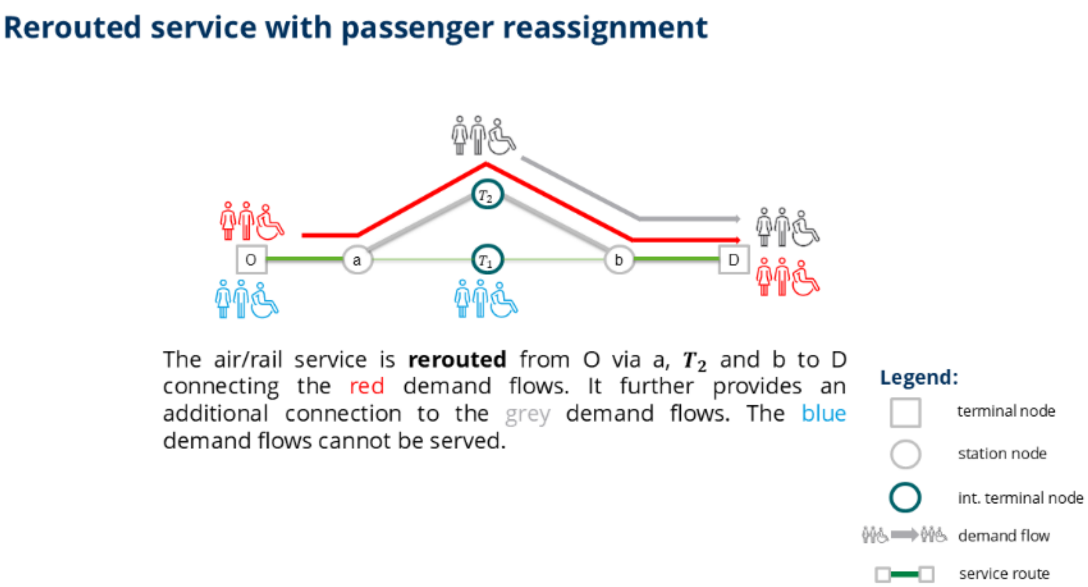

Figure 7: Rerouting of services

Based on the passenger flows and the corresponding service adaptations, the disruption management solution provides the air and rail schedules of the network (i. e. the replanned network) w.r. to the provided disruption events. Thereby, the solution allows replan operations on the day of operation but also as contingency plans at D-1 when defining the ATFCM Daily Plan (ADP) and ATFM regulations are planned/known supporting DCB activities. The solution is thus triggered whenever operators gain knowledge of upcoming disruptions (i. e. major adverse events, which are likely to cause significant delays/capacity limitations) in one or multiple parts of the network. Some examples could include adverse weather or reparation (ad-hoc maintenance) closures. Note that by the nature of this, i.e., if a replanning of a set of operations is conducted due to a disruption, some lookahead time is expected.

3.3.2.3 Use cases

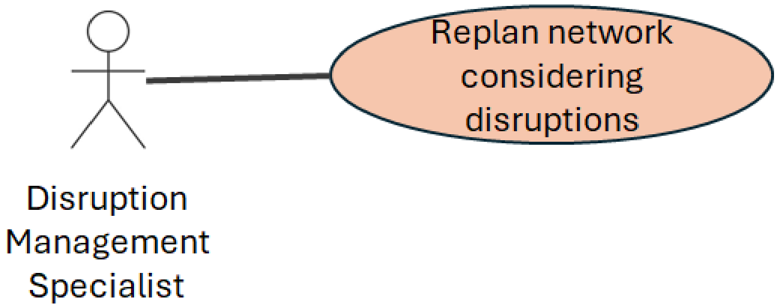

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Figure 8: SOL401/SOL401 – Use Cases diagram

Figure 8 presents the use cases diagram for SO401/SOL401. As shown, there is only one Use Case: *Replan network considering disruptions*. This Use Case is triggered and interacted by an abstract role 'Disruption Management Specialist', which could represent a specialist interested in replanning the network, either within the (Muldimodal) Network Manager, or as part of any of the other relevant stakeholders (e.g. within Airspace Users, Rail Operators, or even Airport Management) to assess the impact of possible 'what-if' disruptions. Note that all data formats and requirements are described in Annex A – Input/Output formats from the FRD [17].

Use case: Replan network considering disruptions

Primary actor: Disruption Management Specialist

Scope: Disruption Management Model

Stakeholders and interests:

- Disruption Management Specialist: wants to generate coordinated, adjusted schedules between rail and air considering air and/or rail disruptions. The Disruption Management Specialist could be part of the Network Manager (air, rail or multimodal), and/or airline, rail, airport, infrastructure specialist.

Brief: The Disruption Management Specialist uses the Disruption Management Model to create optimised adjusted flight schedules and rail timetables considering a set of air and/or rail disruptions (disruption package).

Preconditions: Air and rail demand data is available and in the required format. The airline and the railway company are collaborating (as stated in assumptions A5 and A7). Disruption information is provided. Information on services (flight schedules and rail timetable) and infrastructure are provided.

Minimal guarantee: The updated schedules and rail timetable respect the infrastructure capacities as defined in the disruptions.

Success guarantee: New adjusted schedules and rail timetables are generated, which potentially minimize the impact on passenger itineraries.

Trigger: The Disruption Management Specialist wants to generate adjusted schedules between rail and air as new disruptions in the air and/or rail network are planned.

Main success scenario:

1. The Disruption Management Specialist provides the Disruption Management Model (SOL401) with the flight schedules, rail timetable, passenger itineraries, infrastructure data, disruption package to be applied, and other configuration information required.

2. SOL401 provides adjusted schedules and rail timetables considering the information provided, respecting the infrastructure limitations (and disruptions), and potentially minimizing the impact on passenger itineraries.
Use case data: • Flight schedules: flight schedules for the day of assessment (see Annex A from FRD [17] for information on format) • Rail timetables: Rail timetables (in GTFS format, see Annex A from FRD [17] for information on format) • Disruption package: Set of disruptions that are applied at the same time to the planned network. • Disruptions: Rail or air network disruptions which are known in advance and produce a significant reduction in supply on the infrastructure of the networks. • Infrastructure data: Minimum connecting times, access and egress times, inter-modes connecting times, and passenger processing times (see Annex A from FRD [17] for information on format and detailed data description). • Passenger itineraries: Number of passengers assigned to an itinerary. • Other configuration information: Any other information required by the Disruption Management Model, such as the availability of coordination between air and rail operators, i.e. centralised or decentralised (see Annex A from FRD [17] for information on format and detailed description).
Auxiliary definitions: • Adjusted flight schedules: Flight schedules modified by the Disruption Management Model. • Adjusted rail timetables: Rail timetables modified by the Disruption Management Model. • Air and rail demand data: origin-destination demand of passengers using air and/or rail services. • Air network disruption: Significant ATFM regulations applied at airports. • Itinerary: A succession of services which respect the minimum connecting times of the services involved. • Services: a particular flight or train. • Rail network disruption: Reduced throughput at nodes (rail stations) and/or links, and/or closure of links.

3.3.3 Differences between new and previous operating methods

SOL401 provides a model to manage multimodal disruptions, which generates replanned air and rail schedules for given scenarios. Also, SESAR solutions that impact the schedules and/or infrastructure (e. g., capacity, MCTs, etc.) could use this platform to evaluate their impact on disruption management, e.g. performance of the new infrastructure connections and/or alternative, original schedules. Further,

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SESAR solutions which manage (unimodal) disruptions could assess their impact on multimodal travel or use the platform's solutions as benchmarks for multimodal disruption management.

As shown, SOL401 enables the replanning of operations (flight schedules and rail timetables) during the Pre-Tactical Flow Management phase, facilitating the uptake of CDM procedures to adjust the demand (flight schedules) prior to operations. This would reduce the need (and intensity) for ATFCM initiatives during the day of operations. The replanning is done considering passenger needs, these are obtained from the planned itineraries; but as previously indicated the DMM solely requires the OD demand; therefore, with small changes on the operational approach, different implementations could be provided enabling different levels of data-sharing requirements (e.g. full passenger itineraries or just estimated origin-destination demand). This might facilitate the deployment of SOL401. Note that the reallocation of passengers in the replanned network is still performed by the Airspace Users and Rail Operators, and nominal disturbances and day-to-day delays are still managed as in current operations. The consideration of passengers' travelling needs is a step forward with respect to the simple allocation of delay performed in the previous operating method.

SOL401 also enables the replanning of operations with a longer lookahead time, even during the Tactical Flow Management phase on the day of operations. Overall, SOL401 could provide information to replan operations in a collaborative and informed manner when significant disruptions are expected in the system.

With respect to the previous operating method, SOL401 opens the door also for the assessment of 'what-if' scenarios to create operational plans that could be deployed in case of severe disruptions in the system considering passenger-trips and needs.

4 Key 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 travelers.	Extensive research has been conducted to ensure that those passenger archetypes represent the variety of travelers.	Medium
A4	Data availability	It is assumed that the required data (demand for each passenger archetype, travel times, infrastructure capacity, passenger preferences, 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	The interest of the project lies in studying the impact of a multimodal and collaborative framework.	High

		between modes of transport (shared data, information, incentive…).		
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 schedule optimization.	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 schedule coordination 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
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

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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
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

5 References

5.1 Applicable documents

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

Content integration

[1] ...

Content development

[2] ...

System and service development

[3] ...

Performance management

[4] ...

Validation

[5] ...

System engineering

[6] ...

Safety

[7] ...

Human performance

[8] ...

Environment assessment

[9] ...

Security

[10] ...

Project and programme management

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

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

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Appendix A Stakeholder identification and benefit impact mechanisms (BIM)

A.1 Stakeholders identification and expectations

Examples of relevant stakeholders include:

- Air and rail operators could create the best disruption mitigation strategies taking into account the passengers being impacted by delays and missed connections. They could also evaluate the potential number of passengers needing rebooking on specific services. They can also assess the resilience of their schedules and timetables with respect to diverse disruptions. They are the primary users of the Solution. They are positively impacted by the implementation of coordinated disruption management between air and rail. Potential benefits include, improved occupancy of trains/planes, better use of resources, minimisation of costs, improved passenger mobility, etc during disruptions.
- Airports: If improved schedules are implemented, airports might expand their catchment area (due to greater connectivity). This is likely to impact positively the number of people visiting the airport in a day. On the contrary, if waiting times are reduced, airports might see a slight decrease in spending from travellers.
- Infrastructure managers could assess how changes in the operation of their infrastructure could impact passenger experience (delays and missed connections).
- GDS (Global Distribution Systems) organisations (Amadeus) could use SOL401 for a better tactical integration of multimodality in transport search engines.
- European and national authorities, regulatory bodies (National and regional governments, European Commission, other decision makers, ERA, EU Joint Research Centre, OECD) could use the results of SOL401 for the decision processes of future policies and the integration of multimodality.
- Cities and regions, urban planners (ARC regional council members) could use the results of SOL401 to serve as a basis for decision making in the development or improvement of certain infrastructure and urban planning at the city level.
- SESAR JU: could use the the Disruption Management Solution to assist the stakeholder in more effectively managing for the tactical multimodal coordination.
- The research community can use the Disruption Management Solution for further research and deepening of the themes covered within the scope of the Solution. Moreover, the results can serve as the basis to direct and justify future research.

A.2 Benefits impact mechanisms (BIM)

Tables A1 and A2 summarises the solution benefits showing the benefit impact mechanisms (BIMs) impact (positive, negative or neutral). The details are defined in SOL401 ECO-EVAL, Section 4.

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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 A.1: 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 A.2: KPIs/PIs developed by the project where the SOL401 can benefits.

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