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Travel Information Management for Seamless Intermodal Transport: Lessons Learnt from the TRANSIT Project and Way Forward

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TRANSIT

TRAVEL INFORMATION MANAGEMENT FOR SEAMLESS INTERMODAL TRANSPORT

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Abstract

This document gathers the main results and the lessons learnt of the TRANSIT project. The project has delivered three Solutions: the TRANSIT Intermodality Assessment Framework, which enables the evaluation of the impact of innovative intermodal transport solutions on the quality, efficiency and resilience of the door-to-door passenger journey; the TRANSIT Intermodal Timetable Synchronisation solution, which enables the design of synchronised timetables between air transport and ground public transport modes; and the TRANSIT Intermodal Disruption Management Tool, which provides a mechanism for information sharing and coordination between ATM and ground transport suppliers for the tactical management of unplanned disruptions in the airport access modes. This document describes each of these solutions, deriving conclusions, recommendations and avenues for future research aimed at paving the way to seamless integration of aviation into the multimodal European transport system.

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1 Introduction

The provision of seamless multimodal door-to-door travel options is a priority for the European transport policy. Accordingly, the long-term vision for the European aviation sector outlined in the report 'Flightpath 2050 - Europe's Vision for Aviation' envisages a passenger-centric air transport system thoroughly integrated with other modes and able to take travellers and their baggage from door to door predictably and efficiently, making it possible for 90% of travellers within Europe to complete their door-to-door journey within 4 hours. One of the key requirements to realise this vision is the development of interconnected platforms and services that enable coordinated planning and collaborative decision-making across transport modes through the sharing of information at both the strategic (e.g., schedule synchronisation) and the operational level (e.g., disruption management).

The TRANSIT project aimed at providing the aviation sector with a set of multimodal key performance indicators (KPIs), mobility data analysis methods and transport simulation tools enabling the evaluation of the impact of innovative intermodal transport solutions on the quality, efficiency and resilience of the door-to-door passenger journey. To this end, the project has developed a multimodal performance assessment framework based on cutting-edge approaches to mobility data analysis and agent-based transport simulation, designed to monitor multimodal indicators and provide reliable estimates of how intermodal transport solutions would improve such indicators. TRANSIT has also proposed two specific intermodal solutions to enhance the integration between air transport and airport access modes: the TRANSIT Intermodal Timetable Synchronisation solution, which enables the design of synchronised timetables between air transport and ground public transport modes; and the TRANSIT Intermodal Disruption Management Tool, which provides a mechanism for information sharing and coordination between ATM and ground transport suppliers in the event of unplanned disruptions. The assessment framework has been used to simulate and assess the performance impact of these two solutions, showing their great potential to improve the multimodal passenger experience.

In the following pages, the reader will get an overview of the multimodal performance assessment framework and the two intermodal transport solutions proposed by TRANSIT, as well as of the insights gained on the benefits that these solutions can entail for the overall transport system. The document also provides a set of key takeaways and a look to the future of intermodal solutions in air transport. For more detailed information on the project outcomes, we invite the reader to download the technical deliverables available at the project website: https://www.transit-h2020.eu/.

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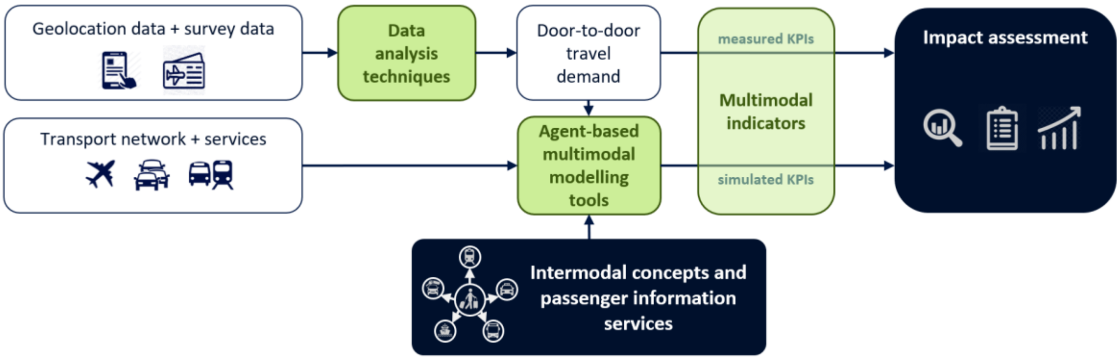
2 TRANSIT Intermodality Assessment Framework

2.1 The concept

The **TRANSIT Intermodality Assessment Framework** enables the evaluation of the impact of innovative intermodal transport solutions on the quality, efficiency and resilience of the door-to-door passenger journey. The framework offers a set of multimodal, passenger centric, door-to-door performance indicators, a set of data analytics techniques for the detailed reconstruction of long-distance multimodal trips, and an open-source agent-based simulation framework that integrates a long-distance travel demand model with a model of airport access transport network.



2.2 Components of the framework

2.2.1 Multimodal performance indicators

The assessment of intermodal solutions must be based on **indicators that take into account the interdependences between journey legs**. Ground transport assessment frameworks offer approaches to deal with multimodal transport systems in urban contexts, but they often focus on a single dimension and they lack a standard structure. ATM assessment frameworks are unimodal by nature, but they provide a valuable structure for a systematic assessment of the passenger experience and journey impacts. The multimodal performance indicators proposed by TRANSIT combine ground transport methods with ATM's systematic approach to performance analysis.

Moving from unimodal to multimodal indicators requires reflecting upon how each dimension of the journey is affected by the interdependences between its legs. This leads to three complementary strategies to develop multimodal indicators: (i) **additive indicators (+)**, when the journey value is the sum of the unimodal values for the different legs (e.g., average travel time); (ii) **weakest link indicators (W)**, when the journey value is the unimodal value of the worst link (leg), regardless of the characteristics of the other legs (e.g., safety); and (iii) **door-to-door indicators (D)**, when the journey value is neither the sum of the legs nor a single leg value, due to the correlation between journey legs (e.g., travel time reliability).

The list of indicators is organised by up to 11 Key Performance Areas (KPAs) covering both passenger experience and system performance.

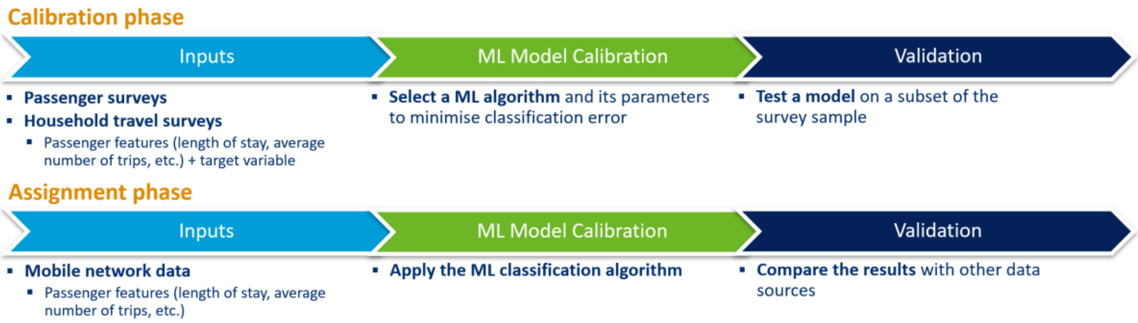
KPA	Indicator	Type	KPI/PI
Safety	Accident ratio	+	KPI
	Perceived safety	W	PI
	Social distancing index	W	KPI
Capacity	Maximum number of passengers for an OD considering all the alternatives	W	PI
	Maximum number of passengers on an alternative	W	PI
Resilience	Capacity reduction	W	PI
	Time required to start to recover	W	PI
Efficiency	Time required to restore normal operation	D	KPI
	Fastest average travel time	+	PI
	Total Travel Time	+	KPI
	Ratio TTprivate / TTtp	+	PI
	Ratio In-vehicle Time / Total Travel Time	+	PI
	Ratio Waiting Time / Total Travel Time	+	PI
	Ratio Transfer Time / Total Travel Time	+	PI
	Ratio Access time / Total Travel Time	+	PI
	Pax time efficiency - best possible journey time/actual time travel	+	PI
Environmental	CO2 per passenger-km	+	KPI
	NOx per passenger km	+	KPI
	PMx per passenger km	+	KPI
	Used land	+	KPI
	% of people exposed to harmful noise	+	KPI
Cost effectiveness	Direct cost	+	KPI
	Indirect costs	+	KPI
	Bundle costs	+	PI
Predictability and punctuality	Travel time variability	D	PI
	lambda skew	D	PI
	Buffer Time	D	KPI
	Temporal Variability Index (TVI)	D	PI
	On-time performance (OTP) - ratio on time trips vs all trips	D	KPI
	% of cancelled trips - when there is no other plausible option	D	KPI
	Potential Wait Time	D	KPI
	Maximum GEH_t (T90 and Taverage)	W	PI
Security	Traveller assault (crime) rates	+	PI
	Perceived traveller assault risk (crime)	W	PI
	Cyber security	W	PI
Accessibility and Equity	4-hour reach	D	PI
	Disabled access	+	PI
	Affordability	+	PI
Flexibility	Number of options to make a trip	+	PI

KPA	Indicator	Type	KPI/PI
Interoperability	Number of legs	+	PI
	Number of modes	+	PI
	Number of required tickets	D	PI

2.2.2 Measuring indicators: how to monitor passenger behaviour?

The impact of intermodal solutions depends on how they are aligned with passenger needs. In a context of dynamic passenger demand and changing transport systems, the aviation sector requires **up-to-date and fine-grained information on passenger behaviour**. Passenger surveys provide valuable data, but they are often limited in sample size and too costly to move from cross-sectional snapshots to passenger behaviour monitoring. Geolocation data, which accounts for the wide variety of digital traces passively generated by passengers produce along their journey, have opened new opportunities for understanding passenger needs. The anonymised records collected by mobile network operators from the interaction between mobile devices and the antennas of the mobile network (mobile network data) are particularly interesting for this purpose, as they enable a detailed analysis of the door-to-door journeys of large passenger samples.

However, this rich data source faces some limitations: it often lacks key information on passengers and their journeys, such as age, gender, trip purpose and airport access mode. To overcome these limitations, TRANSIT has developed a set of **data fusion and machine learning methods to combine passenger surveys and geolocation data**. These techniques exploit passenger surveys to capture the relationships between the passenger and journey attributes missing in the mobile network data and the explanatory variables that are available from both sources, so that the missing variables can be estimated. TRANSIT has applied this approach to target variables such as age, gender, car availability, trip purpose and airport access mode.

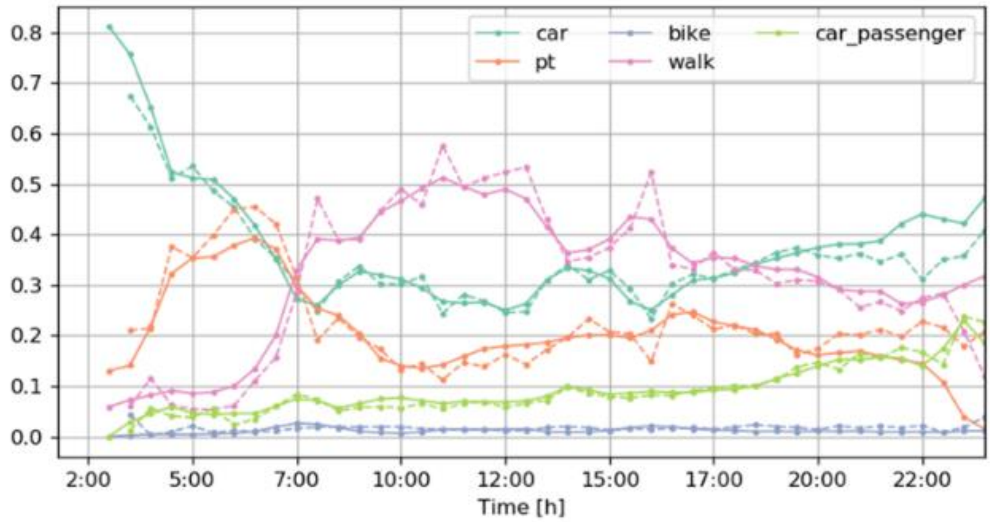


2.2.3 Modelling indicators: how to anticipate the impact of intermodal solutions?

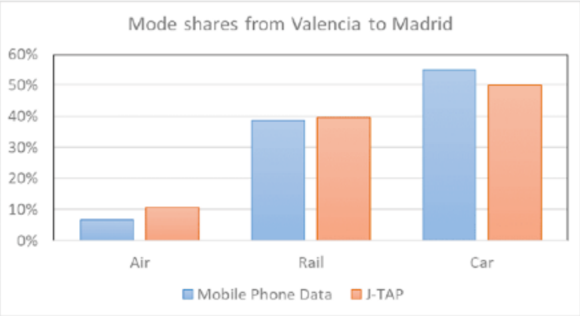
The measurement of multimodal indicators is of paramount importance to understand how passenger behaviour evolves and evaluate the impact of intermodal solutions once they are implemented. However, the aviation sector also requires methods to **anticipate the effects of intermodal solutions on passenger experience and system performance**, in order to move from trial-and-error to evidence-based multimodality policies. Agent-based transport simulation, an approach that reproduces the choices and behaviours of each individual passenger, provides a natural framework to simulate these solutions and their impacts on passenger-centric indicators. Historically, agent-based modelling of transport systems has been largely limited by the paucity of disaggregated information on passenger behaviour. The increasing availability of this information thanks to enriched geolocation data, such as mobile network data, is helping eliminate this barrier.

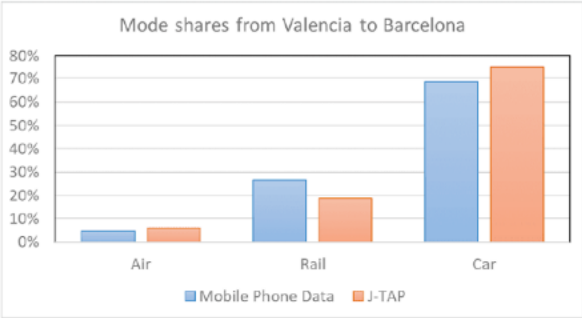
TRANSIT offers a **bi-layered modelling framework that combines two agent-based transport simulation tools**:

- **MATSim**, a daily travel simulator suitable for airport access modelling. TRANSIT has evolved MATSim to include “within-day replanning” mechanisms that improve the realism of how passengers react to unplanned disruptions in the airport access transport network. The figure below illustrates the calibration results of the Paris MATSim model developed by TRANSIT, comparing modal shares by time of the day as reported by a household mobility survey (dashed lines) and by the TRANSIT model (solid lines).



- **J-TAP**, a long-distance travel simulator suitable for the modelling of door-to-door journeys. TRANSIT has developed new graph-based approaches to the representation of multimodal transport networks that have turned J-TAP into a multimodal model. The figure below illustrates the calibration results of the Spain J-TAP model developed in TRANSIT, comparing modal shares in two origin-destination pairs as observed through mobile network data and as modelled by J-TAP.

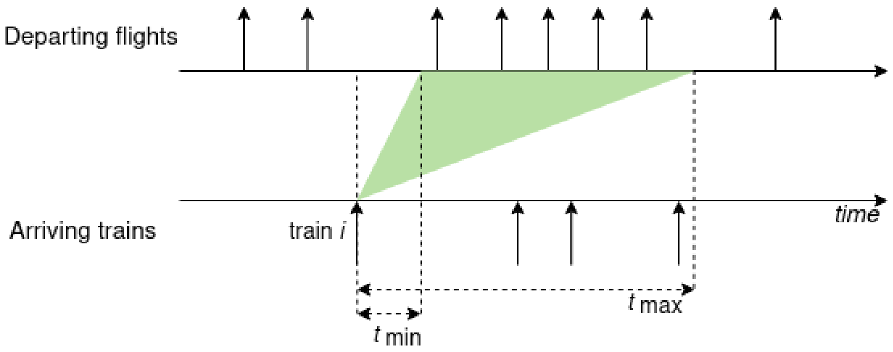

Mode shares from Valencia to Madrid
60%
50%
40%
30%
20%
10%
0%
Air
Rail
Car
Mobile Phone Data
J-TAP


Mode shares from Valencia to Barcelona
80%
70%
60%
50%
40%
30%
20%
10%
0%
Air
Rail
Car
Mobile Phone Data
J-TAP

3 TRANSIT Intermodal Timetable Synchronisation

3.1 The concept

The **TRANSIT Intermodal Timetable Synchronisation** solution enables the design of coordinated timetables between air transport and ground public transport modes. The solution consists in an algorithm that generates a timetable that optimises the connection times between flights and ground public transport services so as to find the best possible trade-off between reducing door-to-door travel times and minimising the risk of missed connections in the case of delays.



3.2 Assessment of the Intermodal Timetable Synchronisation solution

3.2.1 What we try to find out

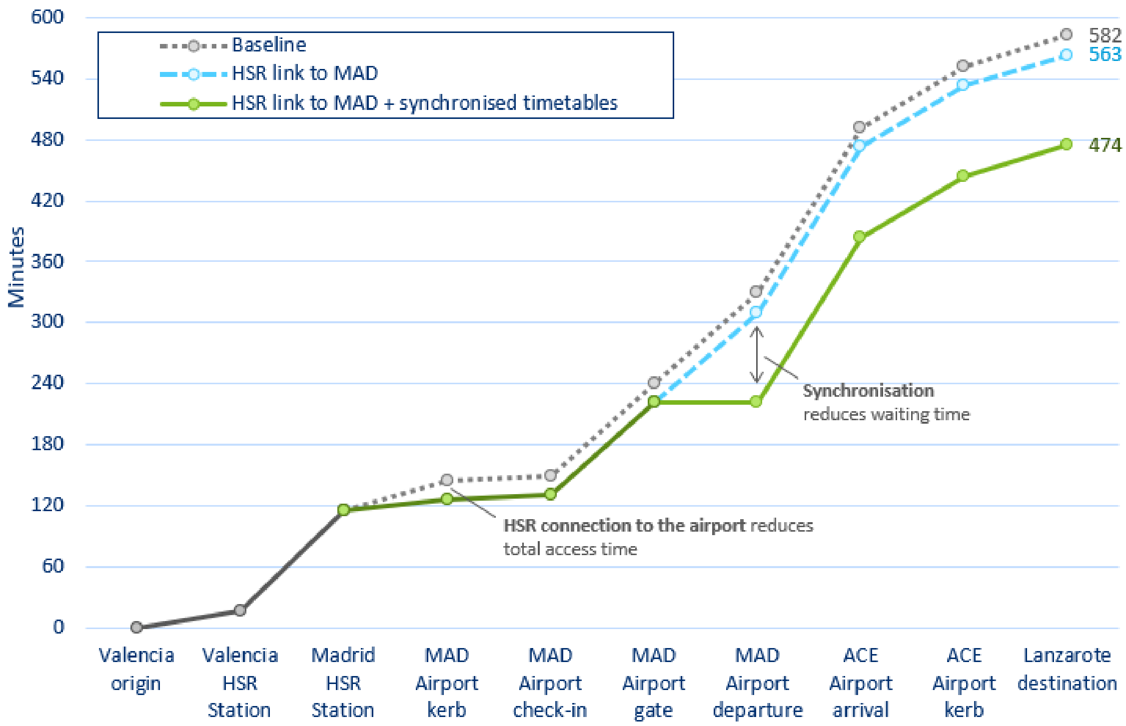
Many hub airports have large catchment areas, particularly for international flights and for continent-island domestic flights. In a context of limited multimodal integration, private car and connecting short-haul flights account for a wide proportion of the access and egress legs to/from hub airports. This increases the carbon footprint of air transport, adds extra road traffic to congested airport access networks, and limits the airport capacity available for much demanded long-haul flights.

High-speed rail services are seen as an opportunity to improve long-distance airport accessibility that can enlarge catchment areas and reduce door-to-door travel times while reducing CO2 emissions. However, it remains unclear if 'hard' infrastructure measures (e.g., adding a high-speed rail link to an airport) are enough or even worthwhile if they are not accompanied by 'soft' measures such as integrated ticketing and coordinated scheduling. **TRANSIT has tested how timetable synchronisation can help improve connectivity by offering more environmentally friendly options to perform door-to-door journeys**. The TRANSIT Intermodal Timetable Synchronisation solution has been applied to a case study focused on a Spanish continent-island domestic connection: Valencia-Lanzarote. Valencia Airport (VLC) serves the third largest metropolitan area in Spain (1.6 million inhabitants) and Lanzarote Airport (ACE) serves the third island of the Canary Islands with most tourist activity. As there is no direct air connection, passengers are routed via Madrid Barajas Airport (MAD). Three options are available for the Valencia-Madrid Barajas leg: using a private car, taking a connecting flight, or combining the high-speed rail connection to Madrid city centre with metro, commuter rail or taxi to reach the airport. The analysis considered three scenarios: current conditions, high-speed direct connection to MAD (as already planned to be built), and high-speed direct connection including the timetable synchronisation solution developed by TRANSIT.

3.2.2 Key results

Improvements in multimodal accessibility and passenger experience

Timetable synchronisation allows the rail-air alternative to become the fastest option to perform the Valencia-Lanzarote journey (7h54'), cutting by 15% the baseline travel times offered by road-air and air-air options. The travel time savings associated with the synchronisation multiply by 5 those associated with the planned direct link of Madrid Barajas Airport to the high-speed rail network, unveiling the importance of combining infrastructure investments with multimodal management strategies.



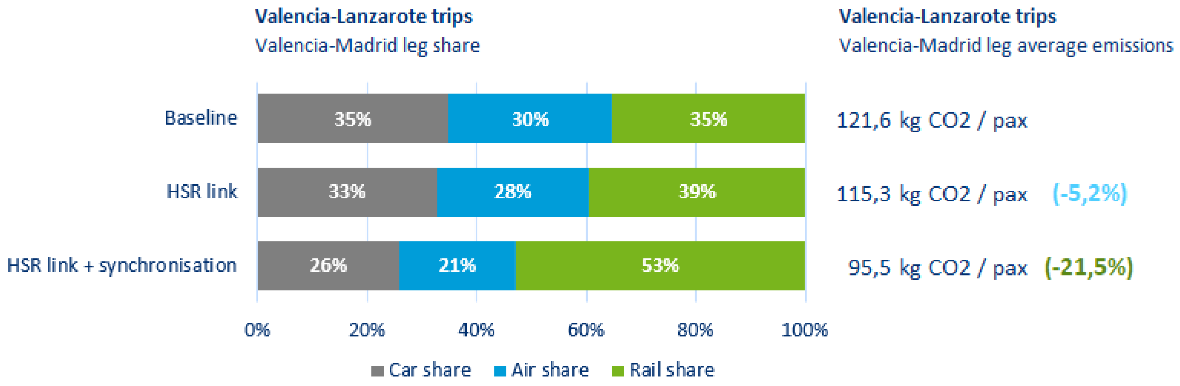
The travel time savings achieved for the rail-air option thanks to the synchronisation do not only improve accessibility but also passenger experience, as they come from savings in those stages of the journey that are perceived as least purposeful by passengers: the in-vehicle/total travel time ratio increases from 45% to 55%, as the waiting/total travel time ratio decreases from 41% to 32%, and the transfer/total travel time ratio decreases from 6% to 3%.

Indicator	Rail - Air			Road - Air	Air - Air
	Baseline	HSR link	HSR link + synchronisation		
Passenger time efficiency[1]	81%	84%	**100%**	85%	85%
In-vehicle/total travel time ratio	45%	47%	**55%**	67%	41%
Waiting/total travel time ratio	41%	42%	**32%**	27%	49%
Transfer/total travel time ratio	6%	3%	**3%**	1%	0%

[1] The passenger time efficiency of a journey alternative is defined as the ratio between the door-to-door travel time offered by the alternative and the minimum door-to-door travel time offered by all the available alternatives

Boosting environmentally-friendly options

The J-TAP tool included in the TRANSIT Intermodality Assessment Framework enables an analysis of how passengers would change their choices given the improvement of the rail-air option. Travel time savings would lead to a significant increase of the rail share for accessing Madrid Barajas Airport from Valencia to perform the journeys under study, moving from current 35% to 53%. Timetable synchronisation is proven to be a promising strategy to compete with the flexibility offered by private cars and reduce the need for connecting short-haul flights, thus alleviating airport congestion. The result of this modal shift is a 21.5% reduction of the CO2 emissions associated with this journey leg compared to current levels, outperforming by 16 percentage points the reduction achieved with the direct high-speed rail to the airport link without any timetable synchronisation.



3.2.3 Policy recommendations

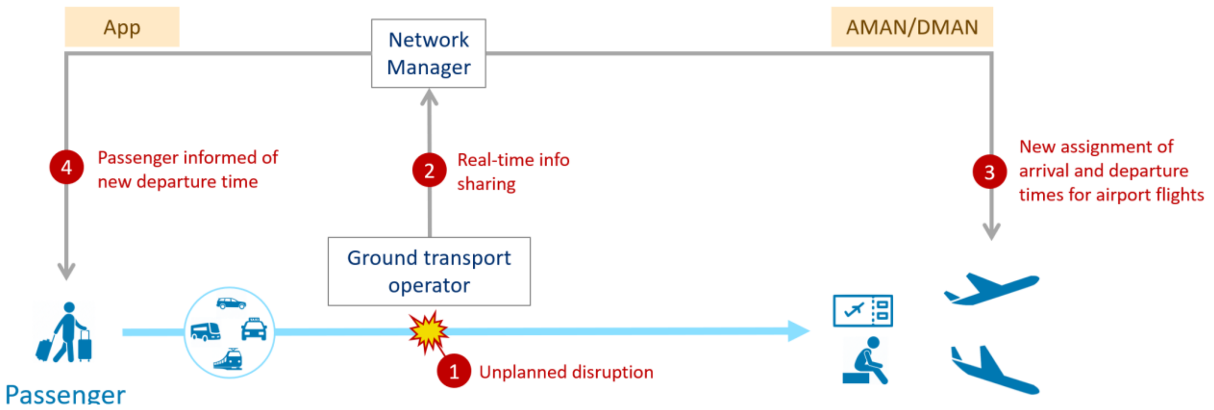
- **Long-distance travel modelling will become a key enabler of multimodal cooperation among transport stakeholders.** Until very recently, the generation of long-distance travel models was a time consuming and costly undertaking usually reserved for large infrastructure investments. The availability of new data sources for passenger behaviour analysis and the advances in the representation of multimodal transport networks changes this paradigm, making it possible to perform ex-ante assessment of intermodal solutions. These models can help airlines, airports and ground transport operators realise the benefits of intermodal cooperation, not only from a passenger perspective (e.g., door-to-door travel time savings) but also from a system perspective (e.g., reduction of GHG emissions).

- **'Soft' measures such as timetable synchronisation are at least as potentially effective as 'hard' infrastructure investments.** The case study conducted in TRANSIT shows that timetable synchronisation can augment the impact of the so-called integration of airports in the European high-speed rail network. Door-to-door travel time savings associated with such connections can be multiplied by 5 if timetables are properly synchronised. This effect would increase the attractiveness of air-rail connections. As shown by the Valencia-Lanzarote case study, the relatively limited shift caused by the direct link can be multiplied by 4 if timetables are synchronised. This would lead to significant emission savings thanks to a more sustainable modal mix in the long-distance access legs associated with long-haul flights.

4 TRANSIT Intermodal Disruption Management Tool

4.1 The concept

The **TRANSIT Intermodal Disruption Management Tool (AMAN/DMAN Ground Tool)** provides a mechanism for information sharing and coordination between ATM and ground transport suppliers for the tactical management of unplanned disruptions in the airport access modes, such as an unexpected rail or subway shutdown.



4.2 Assessment of the Intermodal Disruption Management Tool

4.2.1 What we try to find out

Multimodal airport access networks are subject to unplanned disruptions. Events such as sudden road closures due to accidents and public transport service disruptions have a negative impact on the passenger experience and may even disturb the whole journey if they prevent passengers from arriving in time to catch their flights. At the moment, the impact of these disruptions largely depends on the buffer times planned by each passenger for the journey, on the resilience of the disrupted access mode (i.e., time to recover their nominal capacity) and on the quality of the unaffected alternative options to reach the airport. The vision of a European multimodal transport system includes proactive solutions to mitigate the effects of unplanned disruptions. In the context of air-ground transport intermodality, one potential solution is extending Arrival and Departure Managers (AMAN/DMAN) to implement dynamic flight schedule adjustments aimed at avoiding passengers to miss flights due to unplanned disruptions on airport access services.

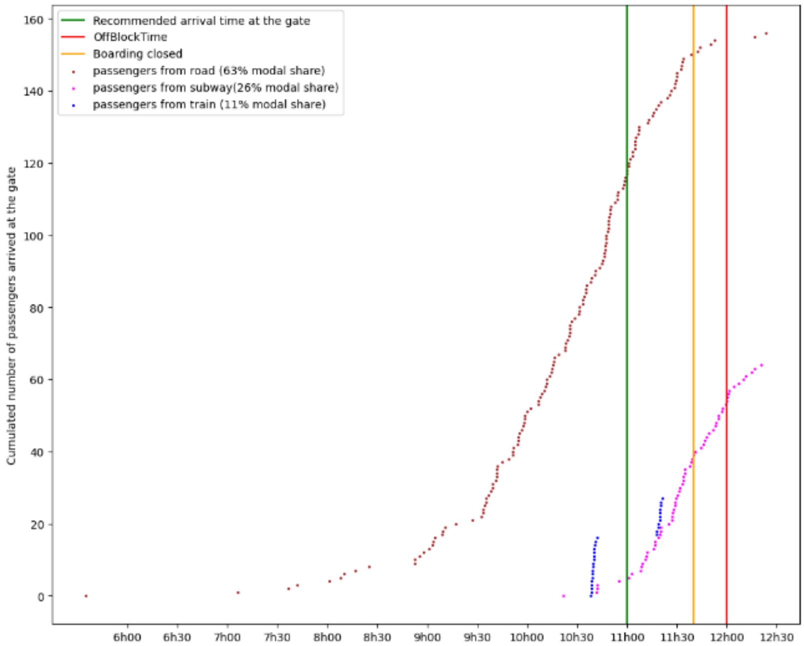
TRANSIT has tested how an AMAN/DMAN Ground Tool could reduce the number of stranded passengers in the event of airport access disruptions without significantly affecting ATM operations. The effects of the proposed AMAN/DMAN tool were tested under different hypothesis on how the passenger receives the information about the disruption, accounting for a variety of scenarios on the implementation of passenger information services.

The TRANSIT Intermodal Disruption Management Tool was applied to Paris Charles de Gaulle Airport (CDG) and Madrid Barajas Airport (MAD). Rail and subway services are a pillar of the airport access transport network in both airports, supporting more than 20% of the access and egress legs. The Paris scenarios included 2-hour, 6-hour and 8-hour disruptions in commuter rail line RER-B (14:00-16:00, 10:00-16:00 and 10:00-18:00), while the Madrid scenario considered a 3-hour disruption in subway line 8 (10:00-13:00). The Paris scenarios considered different levels of passenger awareness on the situation depending on how many of them receive a notification about the disruption before reaching the disrupted mode (0%, 25%, 75%).

4.2.2 Key results

A disaggregated representation of disruption effects

The availability of fine-grained information on passenger behaviour across all journey legs facilitates a realistic representation of the airport access process at an individual level, which is key to understand how each disruption affects the passengers of each flight. The TRANSIT Intermodal Disruption Management Tool offers detailed insights on how the passengers from each access mode are positioned to reach the gate at the recommended arrival time, at the time the boarding closes, and at the off-block time, when boarding is no longer possible at all. The figure at the right illustrates this in a disruptive situation, each dot representing a passenger willing to board a flight with off-block time at 12:00 and boarding time at 11:40. A disruptive event in one of the access modes (subway) may lead to some of the passengers arriving after the gate closes.



Mitigating airports access disruptions without creating network issues on the air-side

The scenarios tested in Paris Charles de Gaulle Airport (CDG) and Madrid Barajas Airport (MAD) show that an AMAN/DMAN Ground Tool can reduce up to 30% the number of passengers that miss their flights due to airport access disruptions with only an average of 1.5 minutes of induced delays on inbound and outbound flights. The simulations, backed by the MATSim tool included in the TRANSIT Intermodality Assessment Framework, show that the largest reductions in the number of stranded passengers due to unplanned airport access disruptions are concentrated in the shortest events, ranging from 6-7% in 8-hour disruptions to 29% in 2-hour disruptions in the Paris case. On the contrary, induced delays are higher in shorter disruptions, but the span between long and short disruptions is short, as average induced delays lie between 1.2 and 1.6 minutes. These figures

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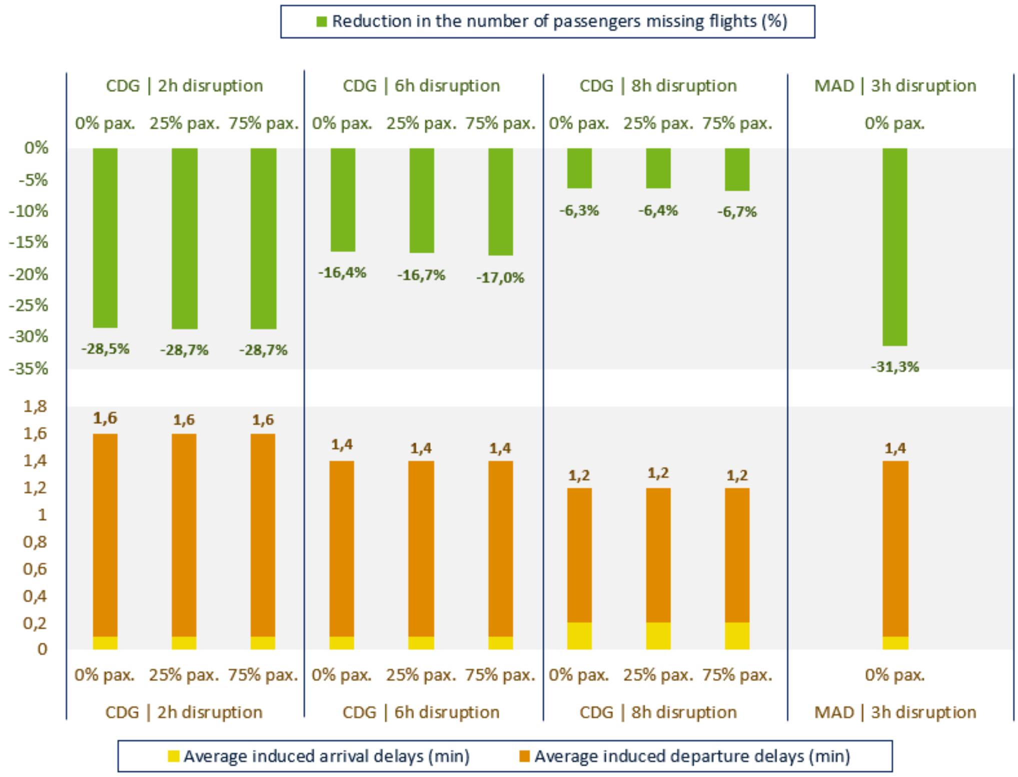
confirm that there seems to be margin to implement such intermodal mechanisms without major impact on ATM operations. The results also suggest that passenger information services have a limited influence on the effect of the AMAN/DMAN Ground Tool. This may deserve future work to refine the sensitivity of the models to this factor, but it may also be related to the resilience of the airport access transport network: the more efficient options are available to passengers, the faster they can re-route to reach the airport on time.



4.2.3 Policy recommendations

- **The resilience of airport access networks mitigates the impact of unplanned disruptions.** Airports whose access transport networks are redundant can better accommodate disruptions. However, redundancies come at the cost of providing more capacity and several access options. In the near future, new mobility services and technologies, such as autonomous shared vehicles, may be an opportunity to provide extra options while optimising existing infrastructures.
- **The extension of AMAN/DMAN to the airport access services can contribute to a better passenger experience without major impact on ATM.** TRANSIT results show that large European hub airports such as Madrid Barajas and Paris Charles de Gaulle can reduce the number of stranded passengers due to typical unplanned disruptions in access public transport services up to 30% with just an average departure delay of 1.5 minutes. The proposed AMAN/DMAN Ground Tool stands out as a promising concept to manage the emergent trade-off between multimodal passenger experience and ATM capacity, which will gain prominence if connecting flights with guaranteed transfers are to be substituted by air-rail integrated services.

5 Key takeaways

- **Multimodal assessment requires air-ground transport transdisciplinary expertise**. This includes the need for a shared language across practitioners, as demonstrated during the definition of indicators.
- **Not all passenger experience dimensions are equally affected by the interdependence between trip legs**. Some KPIs directly result from the addition of the contribution of each leg or are driven by the weakest link; however, there are more complex relationships that can only be understood at door-to-door level, such as travel time reliability.
- **Passively collected data from geolocated mobile devices, such as anonymised mobile network data, enable the monitoring of passenger needs and behaviours with an unprecedented level of detail**, making it possible to move from cross-cutting characterisation of travel behaviour to longitudinal monitoring and early detection of new patterns and trends.
- **Besides monitoring, data pave the way for more realistic simulation models**. The availability of large samples of fine-grained travel behaviour data enables the development of highly realistic agent-based transport models that provide a sandbox for the design and evaluation of new intermodal solutions.
- **Coordinated planning and collaborative decision-making based on information sharing and common situational awareness across transport modes entails great potential to improve the quality, efficiency and resilience of the door-to-door passenger journey**. Opportunities encompass solutions from coordinated network planning (e.g., timetable synchronisation) through tactical management of disruptions.

6 A look to the future

6.1 TRANSIT's vision

TRANSIT's vision is that of a multimodal European transport system where the different modes are seamlessly integrated, so that passengers travel from door to door in an efficient, sustainable and resilient manner.

The indicators, data analysis methods and modelling tools included in the TRANSIT Intermodality Assessment Framework will support the evaluation of the intermodal solutions proposed by different air and ground transport stakeholders, and they have the potential to become part of the **integrated transport network performance cockpit** outlined in the SESAR Strategic Research and Innovation Agenda.

The TRANSIT Intermodal Timetable Synchronisation solution will support the **coordination initiatives of airlines, rail and bus operators** to meet European accessibility targets and improve passenger experience, by providing evidence-based guidelines on how to minimise door-to-door travel times by optimising multimodal schedules.

The TRANSIT Intermodal Disruption Management Tool will become part of a future **transport crisis management tool** to be implemented before 2030, providing solutions for mitigating the impact of unplanned disruptions in multimodal transport systems.

6.2 Future research: a pathway towards TRANSIT's vision

- Enhance the data analysis techniques included in the TRANSIT Intermodality Assessment Framework by **expanding passenger profiling capabilities** (e.g., identification of group trips, classification of passengers according to the baggage carried, household size segmentation) and **exploiting additional geolocation data sources**, such as those generated by innovative airport access services (e.g., shared mobility systems).
- Improve the modelling tools included in the TRANSIT Intermodality Assessment Framework by **strengthening their behavioural foundations** (e.g., modelling of destination attractiveness), making them more **sensitive to passenger information services**, developing **more efficient and robust methods for model calibration** and including specific modules to deal with new airport access options such as **shared autonomous vehicles and urban air mobility**.
- Refine the concepts of the intermodal solutions proposed by TRANSIT, including the management of **multiple destinations** and the consideration of **operational constraints** by the timetable synchronisation solution and the management of **larger flight delays** by the AMAN/DMAN Ground Tool.
- Develop **governance models** regarding air and ground transport stakeholders' responsibilities regarding information sharing and passenger rights in intermodal options.

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