Strategic Multimodal Evaluator for Air-Rail Networks

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27th Euro Working Group on Transportation Meeting (EWGT 2025)

1 Motivation

A platform is needed to evaluate multimodal mobility networks considering the joint operations of air and rail services. This should allow for the assessment of different operational environments and demand conditions to facilitate the evaluation of what-if scenarios, which consider changes in any of the parameters that impact the network, such as flight schedules, rail timetables, connectivity infrastructure, integrated ticketing and operators' alliances, incentivisation (*e.g.* taxation of CO_2 emissions) and/or enforcement policies (*e.g.* flight bans), and passengers demand and preferences.

MultiModX's Strategic Multimodal Evaluator provides this, enabling the calculation of mobility performance indicators (PIs) that can be extracted at different levels (*e.g.* region, infrastructure, operator).

2 Background

MultiModX is an Exploratory Research Project from the Single European Sky & Air Traffic Management Research (SESAR) programme. This article will focus on the approach and capabilities of the Strategic Multimodal Evaluator within and beyond the project's scope. The Strategic Multimodal Evaluator leverages the work performed on previous research with graph-based representation of transport following the developments of the TRANSIT project [1], and it is built upon the work of previous research projects such as Vista and Modus [2, 3].

3 Methodology

The Strategic Multimodal Evaluator provides a platform with flexibility to adjust parameters (*e.g.* connecting times between modes and infrastructure) and with calibrated models for the evaluation of current and new flight schedules, rail timetables and policies. The proposed approach for the evaluation comprises four functionalities, as depicted in Figure1.

The starting point of the evaluation is the definition of regions with their demand (by passenger archetype) between them and the infrastructure (airports and rail stations) that can be accessed from them. For example, we modelled intra-Spain mobility with regions defined at the NUTS-3 level in the case study provided. Note that passengers in a given region can start and end their journeys at any of the infrastructure nodes accessible from the region (even if these might be located outside of them). Adequate access and egress times from each region to each infrastructure node must be provided to estimate representative door-to-door total travel times.

3.1 Function 1

Function 1 in the diagram of Figure 1 uses, therefore, as input the supply characteristics, *i.e.*, flight schedules, rail timetable, minimum connecting time (MCT) between services (intra and inter modes connections considered), access and egress times to infrastructures (airports and rail stations) from the

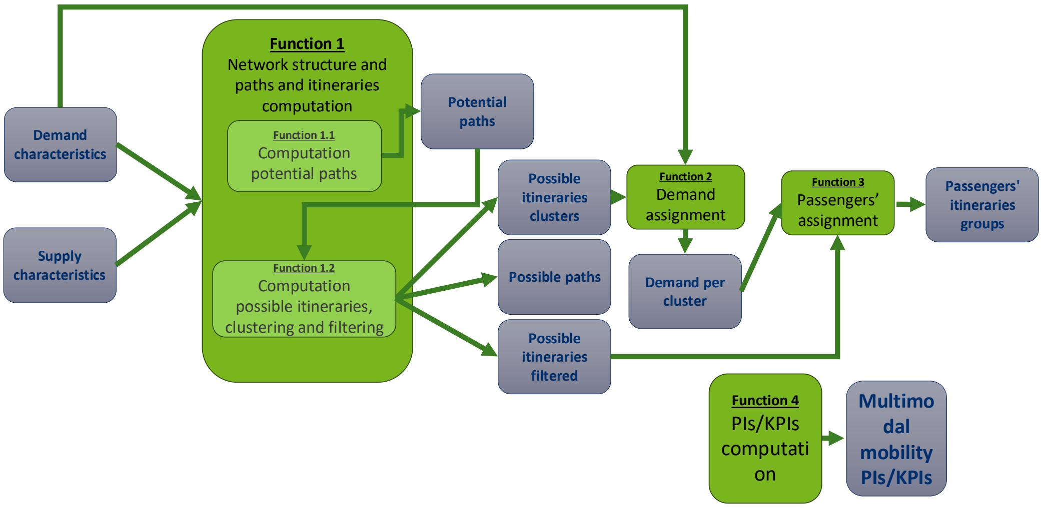

Figure 1: Functional diagram of the Strategic Multimodal Evaluator

regions, alliances and operators integrated ticketing, and the demand characteristics (number of aggregated passengers per passenger archetype for each origin-destination of interest). Note that the flight schedules and rail timetable could come from historical data, the outcome of some optimisation such as timetable synchronisation, the outcome of the impact of some policies (*e.g.* removing flight schedules banned if a short-haul ban is imposed), or even the outcome of replanning operations considering disruptions. Function 1 is composed of two high-level functionalities:

- First, Function 1.1 computes the n-fastest potential paths between each origin and destination. The potential paths do not consider whether the connections of the services are feasible, *i.e.*, respect their MCT, and are computed for two reasons: first, they direct the search of possible itineraries by Function 1.2 (as explained below), and second, the potential paths could be explored by other optimisation solutions to, for example, identify some potential succession of infrastructure nodes (airports, rail stations) which are promising from a mobility perspective.
- Function 1.2 then computes the possible itineraries, considering the service schedules and respecting the MCTs. This search for possible itineraries is done over the potential paths previously computed by Function 1.1. The possible itineraries are then clustered into equivalent alternatives for the passenger's perspective, focusing on mode(s) of transport (*i.e.*, air, rail, multimodal), the number of connections, total travel time (door-to-door), total waiting time, total CO_2 emissions and total travel cost. These clusters are filtered so that only Pareto-equivalent itineraries, with some margins, are maintained per each origin-destination (OD) pair.

3.2 Demand assignment

The overall task of assigning passengers to the individual services (i.e. itineraries) is a difficult optimisation problem. To manage complexity, the problem is divided into Demand distribution (demand distributed/assigned to a cluster of itineraries) and Passenger assignment (demand assigned within the cluster) steps. In the Demand distribution, the demand is distributed per OD pair, alternative, and passenger archetype with the help of a previously calibrated logit model. The logit model is a statistical model which calculates the probability of choosing a specific alternative for each passenger archetype when presented with several options for travelling between a given OD pair.

The probability of an archetype selecting a given itinerary alternative (cluster) is based on a linear combination of total travel time, total CO2 emissions and total travel cost. As shown in the equation below (Equation 1), a utility function is computed for each passenger archetype (a) and alternative (i) between each origin-destination pair.

$$u_a[i] = \alpha_{a\_train} \cdot train_i + \alpha_{a\_flight} \cdot flight_i + \alpha_{a\_multimodal} \cdot multimodal_i + \beta_{a\_time} \cdot travel\_time_i + \beta_{a\_cost} \cdot cost_i + \beta_{a\_co2} \cdot CO2_i \quad (1)$$

Where: - $train_i$, $flight_i$ and $multimodal_i$ are binary variables (1 or 0) describing the itinerary type, i.e., only one of them will be one depending on the modes used in the itinerary. For example, a multi-leg journey where all modes used are flights (e.g. two flights connecting at LEMD on the route LEBL - LEMD - LECO) will be $train_i = 0$, $flight_i = 1$ and $multimodal_i = 0$; while a journey with one leg being a train and a second leg being a flight would be $train_i = 0$, $flight_i = 0$ and $multimodal_i = 1$. - $travel\_time_i$, $cost_i$ and $CO2_i$ are the total door-to-door expected travelling time, cost (Euros) and CO2 emissions (kg) for alternative i respectivelly. Note that in this context, the alternative is the cluster of equivalent individual itineraries, and therefore, these values are the average of all the itineraries within the clusters. - α_{a_train}, α_{a_flight}, and $\alpha_{a\_multimodal}$ represent the sensitivities of the passenger archetype a toward the modes of transport used; β_{a_time}, β_{a_cost}, and β_{a_co2} are the sensitivities of the passenger archetype a towards the total travel time, cost and CO2 emissions respectively.

The logit model, therefore, has different sensitivities depending on the passenger archetypes, and the values of these sensitivities are calibrated based on observed historical demand/trips.

Given an OD pair, the model will, therefore, compute the utility of each alternative, i.e., each cluster, for each passenger archetype, and translate these into probabilities with Equation 2.

$$P_a[i] = \frac{e^{u_a[i]}}{\sum_{j=1}^{n} e^{u_a[j]}} \quad (2)$$

As shown, the probability of archetype a to select alternative i for a given OD pair depends on the utility of that alternative ($u_a[i]$) and the utility of all n alternatives available between the OD pair. Note that different OD pairs might have different numbers of alternatives (clusters) between them. Finally, the demand will then be distributed among the alternatives based on these probabilities.

This demand distribution is performed over the clustered alternatives instead of over the individual itineraries to reduce the number of alternatives for the logit model. The clusters of itineraries are used as a proxy as each cluster contains the itineraries that are equivalent from a passenger's perspective performance (i.e., same (or similar) cost, emissions, total travel time, modes used, number of connections). Therefore, they are equivalent from a passenger archetype preference point of view, and the logit model cannot differentiate between them. Therefore, the result obtained is the flow of passengers who would like to use any of the itineraries of each cluster.

3.3 Passenger assignment

The next step is to assign passengers to the services (flights and trains), considering their capacity (number of seats), to finalise the network loading. For example, given multiple services between A and B with capacity c each, Function 3 must accommodate the total number of passengers between that OD-pair (p), where usually $p > c$. It is important to consider that some passengers may be connecting and, therefore, different itineraries could share some services. The problem is formulated as a lexicographic optimisation problem with the objectives of maximising the total number of connecting and overall passengers assigned and minimising the differences in service load factors and underutilisation. This process will, therefore, disaggregate the flow of passengers into individual itinerary groups assigned to flights and trains.

As shown, the outcome of the Strategic Multimodal Evaluator is the individual passenger's itineraries and the possible itineraries between regions. These datasets can then be processed to compute a set of mobility indicators in Function 4, such as expected travelling time between regions, waiting time, reliability of connections, centrality and connectivity of infrastructure nodes, etc.

4 Case study

This paper focuses on two scenarios, aiming to capture most of the diversity of the multimodal situations across Europe:

The first scope focuses on intra-Spain mobility. This considers passenger demand flows between the 49 biggest cities in Spain (all cities of more than 100 000 inhabitants and all islands which have an airport).

This additional set-up extends the previous one by considering international demand (Spain - International).

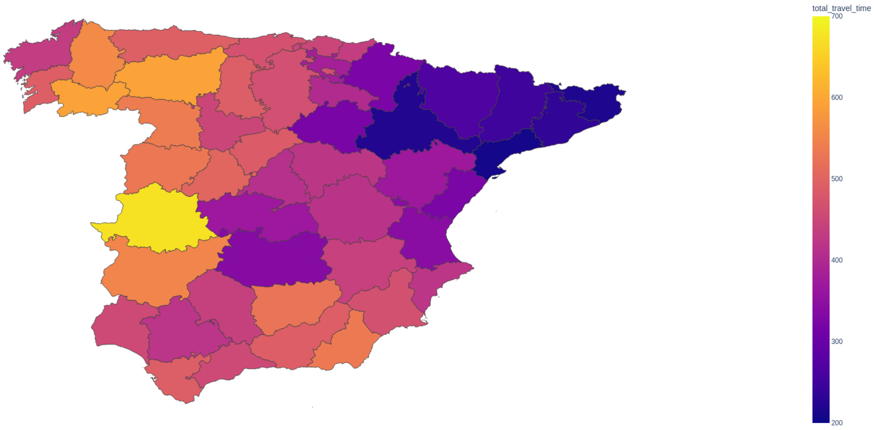

Figure 2: Average travel time from Catalonia to other regions in Spain when a 2h30 flight ban is imposed.

4.1 Multimodality policy incentives

Besides the demand characteristics, the development of multimodal networks is strongly influenced by policies. The current and future European regulatory framework and national policy environments are revised and analysed. In particular, the following policies and their impact on the demand and the supply are considered:

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

5 Results

A case study of intra-Spain mobility will be presented to demonstrate the evaluator's capabilities. A potential policy scenario with a short-haul flight ban is modelled and applied to flights with a rail alternative of less than or equal to 2h30. Figure 2 shows, for example, the average travel time from the Catalonia region (North-East Spain) to other NUTS-3 regions if such a ban is implemented based on possible itineraries available.

The results in the final article will comprehensively analyse the transport network, considering potential mobility between regions and weighted by demand. Examples of indicators include the effect of the flight ban on mobility (comparison of the results with and without the ban), earliest/latest arrival/departure to reach a region from another, the number of alternatives per mode type (air, rail, multimodal), supply excess/imbalance between regions, or possible itineraries allowing x hours at destination in a day. How the model can provide insight into the connectivity of infrastructure (*e.g.* regions reachable from a given airport as a function of different operational considerations) will also be discussed.

6 Acknowledgement

This work has been performed as part of the MultiModX project, which has received funding from the SESAR Joint Undertaking under grant agreement No 101114815 under European Union's Horizon Europe research and innovation programme. The opinions expressed herein reflect the authors' views only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein.

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