

# Generating Multimodal Transfer Hubs and Level-of-Service (LOS) Matrices to Integrate MaaS into Activity-based Models

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## Abstract

The integration of Mobility as a Service (MaaS) into activity-based travel demand models relies on the role of intermodal transfer hubs. Personal mobility depends on seamless combinations of transport modes to reach their destinations. To represent these real travel behaviors, we introduce the concept of *compound modes (CM)*, which combines unimodal segments into an integrated travel chain consisting of access, main, and egress modes. These CM reflect the comprehensive range of common multimodal mode combinations, such as using a bike to reach a public transport stop (access), traveling by train (main), and then walking to the final destination (egress). However, the effectiveness of these multimodal trip chains depends on the availability and functionality of transfer hubs. Transfer hubs serve as critical interchange nodes, enabling seamless transitions between transport modes by connecting different vehicle states (e.g., parking locations and transit stops) Liao et al. (2010). By generating and evaluating these hubs in the context of CM, we ensure that the generated Level of Service (LOS) matrices reflect realistic travel chains, allowing for more reliable integration with activity-based frameworks such as ALBATROSS Arentze and Timmermans (2004) and FEATHERS Bellemans et al. (2010).

The traditional unimodal LOS method ignores multimodal and micromobility options, especially during the first and last mile of a trip, resulting in a limited representation of real travel behavior. A challenge lies in gener-

ating LOS matrices that account for intermodal transfer hubs. To address this, we propose a framework with a focus on two components: identifying transfer hubs based on spatial and service-level criteria, and the use of min-plus algebra to compute LOS values between origin-destination pairs while considering the transfer hubs.

To identify the transfer hubs, we used readily available geospatial data sources, including OpenStreetMap (OSM) for detailed information on parking locations and the General Transit Feed Specification (GTFS) datasets for public transport stops and schedules. Each public transport stop is evaluated for its suitability to serve as a transfer hub based on five service quality and connectivity factors: (a) total number of trips served, (b) service hours, (c) peak frequency, (d) number of unique routes, and (e) availability of night service. For each factor, a score between 0 and 1 is assigned using min-max normalization, ensuring comparability across different scales. These individual normalized scores capture how well each stop performs relative to others.

After normalizing, a composite score is calculated for each stop by multiplying the five individual factor scores. To classify these stops, we use a boxplot-based approach. Only scores falling in the fourth quartile (Q4) are considered strong candidates. This upper range is then further subdivided at its midpoint to define two categories: Excellent and Good stops. All stops with composite scores below Q3 are classified as Poor candidate hubs. In this study, only stops categorized as Excellent and Good are retained for further analysis, ensuring a focus on high-quality transfer points.

Next, isochrone maps that represent actual walking distances are generated for each stop using the OpenRouteService API. These isochrones help to select nearby public parking areas and bike stations that can be reached on foot within a reasonable time frame (5 minutes walking) from each stop. This approach captures individual transferability from nearby parking and bike facilities to the public transport stop. After identifying these facilities, any stops lacking essential amenities such as parking are excluded from the final set of candidate hubs. Finally, for each remaining candidate hub, we assign a walking distance from each associated parking or bike station to the nearest stop.

For each CM in our first model, we identify only one transfer hub that can be located either near the origin or near the destination, depending on the structure of the mode sequence. Transfers involving walking e.g., W,C or C,W are handled implicitly, so only transfers between non-walking modes

will be considered a transfer hub. For example, consider the CM (W, C, B), where walking serves as the access mode, car as the main mode, and bike as the egress mode. In this case, the transfer hub where the traveler switches from car to bike will logically be situated closer to the destination. In contrast, if we consider the mirrored CM (B, C, W), where the bike is used for access, the car is the main segment, the transfer point will be positioned closer to the origin.

Selecting transfer hubs, whether near the origin or the destination, helps reducing computational complexity when generating the LOS matrices by excluding infeasible cases early in the process. By focusing on hubs that are most relevant to the specific CM and their spatial relationship to origins and destinations, we avoid unnecessary calculations.

By integrating these spatial and service-level criteria, the framework allows for a realistic representation of the impedance LOS associated with compound multimodal travel chains in activity-based models.

Once we identified the hubs, we use them to determine LOS matrices for CMs required by activity-based modeling. Unlike supernetwork approaches Liao (2019), which translate multimodality into a single graph for shortest-path computation, our method uses min-plus algebra to combine unimodal impedance matrices. Thereto, we make use of **min-plus-algebra** algebra, which provides an efficient method to generate LOS matrices for CMs by combining unimodal impedance components. In order to be clear and concise, the idea is explained briefly by some formal notation.

Let  $\mathcal{H}$  denote the set of hubs and  $\mathcal{T}$  denote the set of TAZs. The procedure consists of two steps:

1. computing unimodal LOS matrices  $M_{T,T}, M_{T,H}, M_{H,T}, M_{H,H}$  for all pairs  $\langle a, b \rangle$  where  $a, b \in \mathcal{H} \cup \mathcal{T}$  i.e. connecting all TAZs and hubs.
2. combining unimodal matrices into multimodal matrices using **min-plus-algebra**. Example for single-hub trips:  $M_{T,T}^1 = M_{T,H} \oplus M_{H,T}$  where  $\oplus$  denotes the *plus* operation in **min-plus-algebra**.

In a multimodal LOS matrix  $M_{T,T}^n$  for  $n$ -hub trips, the element  $M_{T,T}^n[O, D]$  specifies that there exists at least one multimodal solution using  $n$  hubs for which the impedance is as low as  $M_{T,T}^n[O, D]$ .

The resulting unimodal and multimodal LOS matrices are used by activity-based travel plan generators (e.g. FEATHERS) in mode and location choice

models to predict daily travel plans that specify activity locations at TAZs level.

Currently, the single hub case (the most common multimodal case in practice) is being used to feed FEATHERS. Multi-hub LOS matrices are easy to generate. Ongoing research aims to reconstruct multimodal trips in predicted travel plans in order to e.g. assess the use frequency of particular hubs.

*Keywords:* Multimodal transportation, Level-of-service (LOS), Mobility-as-a-Service (MaaS), Transfer hubs, Min-plus algebra

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