Assessing the Role of Traffic Counts in Robust OD Matrix Calibration in Urban Digital Twins

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***Abstract*—Urban digital twins for smart mobility rely on traffic models that can reproduce observed network conditions while preserving the structural information contained in prior Origin-Destination (OD) matrices. In this context, the location and reliability of traffic count sections represent a key issue, since OD calibration depends not only on the number of available counts, but also on their spatial distribution and informative contribution. This work proposes a data-driven methodology to evaluate the role of traffic count sections within a simulation-based OD calibration framework. The calibration procedure regulates admissible variations of OD flows according to demand classes derived from the prior matrix, limiting excessive modifications of high-demand OD pairs while allowing greater flexibility for lower-demand movements. A leave-one-section analysis is introduced: each count section is removed from the calibration set and subsequently used as an external validation point. The effects of each removal are assessed by comparing the resulting calibrated matrix with the full-count baseline and by evaluating changes in the agreement between simulated and observed flows through GEH-based indicators. The methodology is applied to the urban road network of Catania, Italy, using a macrosimulation model and empirical traffic counts from radar sensors and camera-based surveys. The contribution of this work is twofold: methodologically, it integrates OD matrix calibration with an ex-post sensitivity analysis of monitoring sections; practically, it provides evidence that can guide cost-aware criteria for locating traffic count sections in urban digital-twin applications.**

Keywords—OD matrix calibration; traffic sensor placement; leave-one-section analysis; smart mobility; urban digital twin.

I. Introduction

Urban digital twins are becoming a central component of smart-mobility systems, as they provide a dynamic representation of the interaction between travel demand, transport supply, and observed network conditions. In mobility applications, their role goes beyond the assessment of isolated infrastructure or regulatory changes, supporting traffic monitoring, scenario analysis, travel-time estimation, and operational decision-making [1]. The reliability of these applications depends on the ability of the underlying transport model to reproduce observed flows while maintaining a plausible representation of mobility demand.

A critical element in this process is the Origin-Destination (OD) matrix, which describes the spatial distribution of trips across the study area. Prior OD matrices are often derived from historical surveys, previous modelling activities, or administrative datasets. These sources provide a structured representation of demand, but they may become outdated and may not adequately reflect current traffic conditions. More recent data sources, such as floating-car data, mobile-phone traces, or other passively collected mobility data, can improve temporal and spatial updating, although their use may be affected by sampling limitations, penetration-rate issues, and aggregation procedures. For this reason, traffic counts remain a key source of information for OD matrix calibration, especially when they are integrated into simulation-based transport models.

OD matrix estimation from traffic counts has long been addressed through entropy-based, generalized least-squares, and optimization-based approaches, with the common objective of updating a prior demand matrix while improving the agreement between assigned and observed link flows [2]–[4]. More recent studies have further emphasized the role of assignment models, uncertainty, and data-driven information in OD estimation and calibration procedures [5], [6]. In parallel, research on traffic count and sensor location has shown that the spatial configuration of monitoring points affects network observability and the reliability of OD estimation [7], [8]. However, less attention has been paid to the ex-post assessment of the contribution of already available count sections within an operational calibration process, especially when the objective is not only to reproduce observed link flows but also to preserve the structural consistency of the prior OD matrix. This work addresses this gap by introducing a leave-one-section analysis within a constrained OD calibration framework. The aim is to provide evidence on the influence of individual count sections on calibration robustness and matrix stability, thereby supporting the future definition of criteria for the placement and refinement of traffic count sections.

II. METHODOLOGICAL FRAMEWORK

The proposed framework extends the balanced calibration algorithms developed in [9] and combines OD matrix calibration with a sensitivity analysis of traffic count sections. The starting point is a prior OD matrix representing the available knowledge on mobility demand. Since this matrix may not fully reproduce current traffic conditions, it is updated through a simulation-based calibration procedure that compares assigned traffic flows with observed counts on monitored network sections. The calibration procedure seeks to improve the agreement between simulated and observed link flows while preserving the structural characteristics of the prior matrix. To this end, OD pairs are grouped into demand classes according to their prior flow magnitude. Higher-demand OD pairs are assigned tighter adjustment bounds, because large modifications of these movements could distort the original demand pattern. Medium- and low-demand OD pairs are allowed progressively wider adjustments, as changes in these flows have a more limited effect on the overall matrix structure and may help improve the fit with observed counts. For each OD pair, lower and upper bounds are defined according to the demand class of the prior flow. During calibration, candidate matrices are constrained to remain within the feasible region defined by these class-specific bounds. The quality of each solution is then evaluated by considering both the agreement between simulated and observed flows, measured through GEH-based indicators, and the deviation of the calibrated matrix from the prior matrix.

Within this framework, let S denote the complete set of monitored sections. For each section s in S, a reduced calibration set $S^{(-s)}$ is obtained by excluding s from the calibration data. The OD matrix is recalibrated using only the counts observed on $S^{(-s)}$, while the excluded section is retained as an independent validation point. The comparison between the full-count calibration and each leave-one-section calibration makes it possible to assess how the availability of each monitored section affects flow reproduction and matrix stability. For each leave-one-section run, the analysis considers complementary effects rather than relying on a single synthetic score. These include the variation of the recalibrated matrix with respect to the full-count baseline, the deviation from the prior matrix in terms of OD-pair changes and overall demand level, and the variation of GEH-based indicators on the monitored sections. The aim is not to provide a deterministic ranking of count locations, but to identify how the exclusion of each section influences calibration robustness under the specific network and data conditions considered.

III. APPLICATION AND EXPECTED CONTRIBUTION

The methodological framework is applied to the urban road network of Catania, Italy, which represents a relevant case study for testing OD calibration methods in a real urban context. The application is based on a macrosimulation model of the road network and on a prior OD matrix representing the available demand structure for the study area. Empirical traffic counts are provided by radar sensors and camera-based surveys, allowing the calibration procedure to be tested against observed flow conditions on selected network sections.

The implementation follows two main steps. First, a full-count calibration is performed using the complete set of available count sections. This calibration provides the reference solution. Second, each monitored section is excluded in turn from the calibration set, and the OD matrix is recalibrated using the remaining counts. The resulting matrices are then compared with the reference solution to assess the influence of each omitted section on the calibration process.

The expected contribution is both methodological and practical. From a methodological perspective, the proposed framework integrates OD matrix calibration with an ex-post sensitivity analysis of traffic count sections. This makes it possible to move beyond the simple use of counts as calibration inputs and to examine their relative influence on model robustness and matrix stability. From a practical perspective, the approach can support public administrations and mobility managers in refining urban monitoring strategies. Evidence from the leave-one-section analysis can inform future criteria for locating count sections, helping to improve monitoring effectiveness while considering sensors acquisition, installation, operation, and maintenance costs. In the context of urban digital twins, the contribution is relevant because simulation-based decision support depends not only on the availability of traffic data, but also on the spatial configuration and informative role of the monitoring infrastructure. By linking OD calibration performance with the assessment of count sections, the proposed application provides a step towards more transparent and cost-aware monitoring strategies for smart-mobility systems.

ACKNOWLEDGMENT

Traffic count data were provided through the ITS Laboratory of the University of Catania, with V. Torrisi and M. Ignaccolo as scientific coordinators. This work was developed within the framework coordinated by the UISH (Urban Intelligence Science Hub for City Network) project, funded by the Italian Agency for Territorial Cohesion under the POC-PON Metro 2014-2020 programme (CUP: B51B21000430001).

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