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Novel approach for OD estimation based on observed turning proportions and Bluetooth structural information: Proof of the concept

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Abstract

This research proposes a novel approach for estimating OD matrices based on observed turning proportions and Bluetooth structural knowledge. The key idea is to relax the need for explicit assignment-based models and exploit the observations from big traffic data. In the proposed methodology, observed turning proportions implicitly consider path assignment. The methodology is tested on synthetic data from a small network with sufficient route choice options. Numerical experiments are conducted considering different Bluetooth connectivity to OD pairs. The findings from the experimental study indicate that the quality of OD estimates improves as the knowledge of Bluetooth OD increases. The proposed research does not depend on traditional bi-level formulation and is computationally faster. The methodology is adaptive for any data source that can provide OD structural information. The testing of the proposed methodology on a large-scale network is part of the ongoing study.

Key words: Turning Proportions; Non-Assignment; Bluetooth; OD matrix structure, OD estimation

1. Introduction

Origin-Destination matrix estimation has long been the topic of research for many decades. Ever since it has been considered as an optimization problem, many research studies have focused on different solution algorithms to update prior OD by minimizing the deviations between observed and estimated link counts in a bi-level optimization framework. Mostly the bi-level studies dependent on assignment that is either analytically derived (Cascetta 1984) or obtained from simulation (Barceló et al. 2014). For large scale network applications, assignment is almost compulsory as they involve many route choice options. However, with the advent of new sensor technologies, time-dependent vehicle paths can be directly observed, if not thoroughly but to some extent. Based on observed path choices, a few recent studies have tried to circumvent the bi-level approach without the need of assignment. Michau et al. (2017) used observed Bluetooth trajectories in the form of Link-OD matrix within the objective function of OD estimation process. Since, the assignment process is avoided, the non-assignment based OD estimation adopts a single-level optimization framework.

However, there are a few limitations associated with the current state-of-the art for large scale OD estimation. In regards to assignment based methods, there are three major limitations discussed as follows:

1. Firstly, the initial assignment is based on prior OD and both OD and assignment are mutually updated iteratively until convergence criteria is met. If the structure of the prior OD is different from that of true OD then, the convergence criteria might not be met and the convexity condition might not be satisfied (Kim, Baek and Lim 2001).
2. Secondly, the equilibrium assignment might capture congested traffic conditions but it still lacks the ability to estimate an OD matrix that can reproduce observed flows because of errors and inconsistencies of observed link counts. This is because the observed link counts may not always come from an equilibrium traffic state (Fisk 1989).
3. Third, the traffic counts-based approaches suffer from the problem of under-determinacy. The initial studies have tried to address this by using a prior structural knowledge from target OD matrices (Cascetta and Nguyen 1988; Yang 1995). However, the target OD is still an outdated OD.
4. Last but not the least, bi-level approach is computationally expensive, especially for large scale networks, because of the user-equilibrium assignment in the lower level.

With respect to non-assignment methods based on observed path choices, the research is relatively new for large scale OD estimation. For instance, Michau et al. (2017) used Bluetooth trajectories to estimate Link dependent OD matrices by assuming significant penetration of Bluetooth flows, though the rate randomly varies with a Gaussian distribution for all OD flows passing through that link. Since, the penetration of Bluetooth trips is random and unknown, penetration of Bluetooth counts might not be a good proxy for Bluetooth trips.

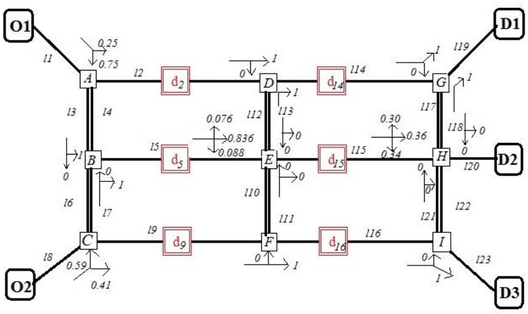
In light of the above-mentioned gaps, objectives of the study are:

1. To relax the dependence on conventional link-proportion (assignment) matrix that maps the relationship between link flows and OD matrix, source of user-equilibrium, and reason for bi-level framework;
2. To relax the dependence on target OD for minimising the under-determinacy problem of traffic counts-based OD estimation problem.

2. Methodology

The study is based on a simple network with sufficient route choice options between OD pairs that can represent realistic traffic behavior (refer Fig. 1 for the sketch of the network). The experiments and the final results are based on this network.

Fig. 1: Sketch of sample test-bed network



2.1 Non-assignment based method to estimate link flows

In the study, paths that are actually traversed by vehicles (in simulation) are referred as *traversed paths,* and the paths that are physically possible are termed as *possible paths*. The same rationale is applicable for the total number of *traversed* and *possible* sub-paths contributing to flows on any link. Based on this background, the authors develop Turning Proportion (TP) matrix from observed turning counts, and propose a method to estimate the link flows instead of depending on the traditional link-proportion (assignment) matrix approach. The cell value of TP represents the proportion of origin flows passing through a particular link.

2.2 Structural knowledge of Bluetooth OD

The study uses additional structural knowledge from Bluetooth OD matrices to maintain structural consistency in OD matrix estimation process. Generally, the spatial coverage of Bluetooth sensors might not be 100% due to which only a certain percentage of OD pairs contribute to Bluetooth structural information. Considering this, let's say M number of OD pairs are Bluetooth connected, and the Bluetooth OD vector and corresponding OD demand vector are $\widetilde{\boldsymbol{B}}$ and $\widetilde{\boldsymbol{X}}$, respectively. The dimensions of both the vectors are $M*1$. The structural comparison of $\widetilde{\boldsymbol{B}}$ and $\widetilde{\boldsymbol{X}}$ is computed using Pearson correlation coefficient and is represented by "*Str*". Note that the OD vector that needs to be ultimately estimated is $\boldsymbol{X}$ (N x N), and $\widetilde{\boldsymbol{X}}$ represents OD flows of those OD pairs that are Bluetooth connected.

2.3 Optimization formulation

The solution algorithm adopted to estimate OD matrix is gradient descent method and is coded in MATLAB. The objective function formulation incorporates both the traditional link counts deviation and the Bluetooth structural knowledge. The search direction is the gradient of the objective function and the step size adapts iteratively to the value of objective function.

3 Experiments and Results

The experiments performed in this study consist of six different cases as follows:
Case-1: This is the traditional traffic counts-based approach.
The rest of the cases i.e. case-2 to case-6, have the structural knowledge of Bluetooth OD incorporated in their objective function for different percentage of Bluetooth connectivity i.e. 33%, 50%, 67%, 83% and 100% respectively.

The results of all cases are further compared using performance measures such as RMSE and coefficient of correlation (*Str*) as shown in **Fig. 2** and **Fig. 3**, respectively. From, **Fig. 2** (RMSE comparison) and **Fig. 3** (*Str* comparison), it can be seen that the chosen prior OD has high error value (102.59) and poor structure (0.2782) as compared with that of true OD. From **Fig. 2**, it can be noticed that there is significant reduction in RMSE value from 102.59 to 67.83 in both case-1 and case-2. However, the improvement in structure is not very significant (*Str* =0.3104 and 0.3105 for case-1 and case-2). This is because no additional knowledge of OD structure is used in case-1 and only 2 OD pairs are Bluetooth connected in case-2 respectively. It is also clear from **Table 1** that some OD demands are overestimated (224.7 for O_1-D_1) and some are underestimated (111.3 for O_1-D_3) for case-1. Thus, only dependence on matching the link counts might not improve the quality of OD estimates if the prior OD is of poor quality. However, with the availability of additional structural knowledge, the quality of OD estimates can be enhanced by maintaining structural consistency despite starting with a poor prior OD. This is demonstrated with different levels of Bluetooth spatial coverage in case-3 to case-6 in **Fig. 2** and **Fig. 3**.

Fig. 2: RMSE comparison: True OD vs prior OD and OD from all cases

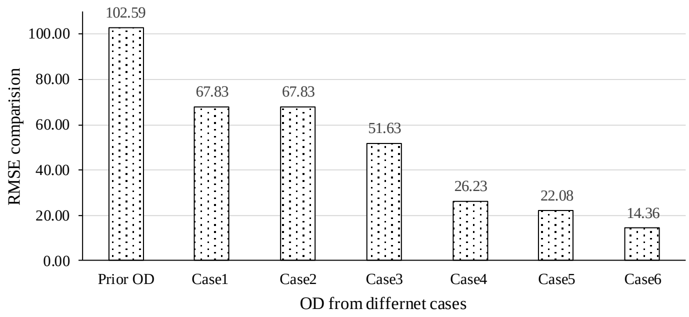


Fig. 3: Str comparison: True OD vs prior OD and OD from all cases

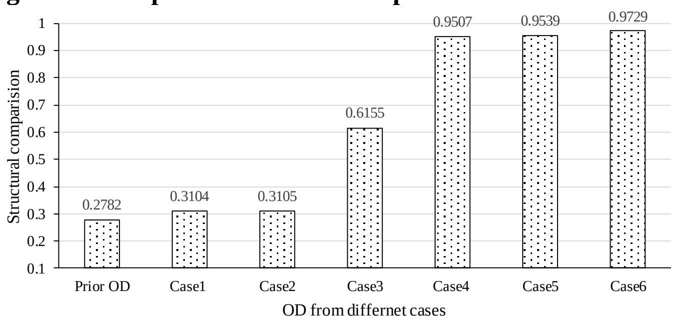


Table 1: Comparison of OD demand flows from all cases with prior and true OD

OD pairs	*X True*	*X Prior*	*X case1*	*X case 2*	*X case 3*	*X case 4*	*X case 5*	*X case 6*
O_1-D_1	107	101	225	225	142	106	108	115
O_1-D_2	91	40	89	89	128	72	84	93
O_1-D_3	227	50	111	111	155	247	233	217
O_2-D_1	199	80	190	190	151	169	174	224
O_2-D_2	92	36	86	86	68	76	74	72
O_2-D_3	199	90	214	214	272	246	242	194

4 Conclusion

This research establishes proof of the concept for a novel approach to estimate OD matrix using observed turning proportions and Bluetooth OD structure. The contribution of the study is twofold:

Firstly, known turning proportions at all intersections relax the dependence on conventional link-proportion based assignment matrix. This implies that there is no bi-level framework anymore.

Secondly, structural knowledge from observed Bluetooth OD matrix is used to maintain structural consistency in OD matrix that is estimated iteratively. This implies that a better estimate can be obtained even with a poor structure of prior OD matrix.

The methodology is tested on a small but a representative urban network with sufficient route choice options between OD pairs. This ongoing research is being extended along following directions:

a) Testing the methodology on large network;
b) Evaluating the computational performance of the proposed approach against the traditional bi-level formulation; and
c) Studying the Bluetooth OD structure based on the variations of the scanner density within different transport analysis zones.

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