

An Enhanced Travel Demand Modeling Framework with a Post-Processing Technique Executed through a Feedback Mechanism

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INTRODUCTION

Travel demand modeling lies at the core of the transportation systems evaluation process. It provides the basis for predicting the need for proposed transportation system improvements (as well as the size and scope of the improvement), and forms the basis for quantifying the costs and benefits of the different alternatives of improvements (Sinha and Labi, 2007). The four-step sequential travel demand model is the most widely used technique in practice which consists of trip generation, trip distribution, mode choice, and traffic assignment. Traffic assignment is a key step of the four-step process which determines the estimated traffic flow pattern in the transportation network, and identifies the volumes and levels of service on the various highways/streets. Generally, traffic assignment problem is solved using the principle of user equilibrium (UE) based on the Wardrop's first principle (Wardrop, 1952) which assumes that network users seek to minimize their individual travel times, which is behaviorally more realistic in a long-term context and is hence mostly used in practice.

Field studies (Goldfarb and Spielberg, 2005; VHB, 2006) have shown that UE assignment has lower errors, on average, when compared to other heuristic assignment methods such as capacity restraint, incremental assignment, all-or-nothing etc. (for details see Sheffi, 1985) in the context of transportation project planning and evaluation. However, there are some key issues related to the four-step sequential demand modeling process and UE assignment that trouble practitioners and planners. A problematic aspect of the four-step model is that origin-destination (O-D) demand acts as input to the traffic assignment (fourth step) but O-D demand is obtained after the second step (trip distribution) that takes travel time (or cost) as the input which is obtained after the fourth step. This necessitates a feedback loop going from the fourth step to the second step as shown in Figure 1. But the feedback loop is typically not used in practice due to two key reasons. First, this loop will increase the computational time significantly, most of which can be attributed to the computational effort required by the traffic assignment step. Second, each iteration of the feedback loop may result in a solution in terms of network flows much different than the results obtained in the previous loop raising the question of when to stop the iterative process. The problematic issues related to UE assignment for practitioners and planners typically are: (i) *stability*: solution outcomes are sensitive to small changes in the network, raising questions of solution stability; (ii) *consistency*: links far removed spatially from the alternative being studied are predicted to have significant changes in volume; and (iii)

convergence: solving the assignment algorithm to stable convergence can require an impractical number of iterations, especially with the commonly-used Frank-Wolfe (F-W) algorithm (Frank and Wolfe, 1956).

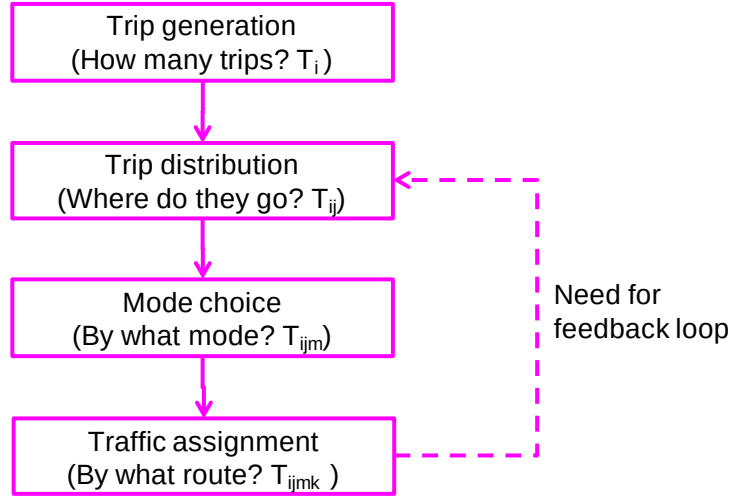


Figure 1: Conventional four-step travel demand modeling process

Travel demand modeling forms the basis for impact analysis of a transportation improvement project and helps in comparing the different alternatives. In many cases, different alternatives may differ by little, but the state of practice of using the sequential four-step method may lead to network flows which differ significantly or suggested improvements which are inconsistent with the network situation. This change in flow can occasionally be realistic but in most of cases arises due to solution noise. There are two main sources of this noise; first, the interdependency between the trip distribution and trip assignment steps, and second, the lower level of convergence in the traffic assignment step (Boyce et al., 2004). Here, we present a methodology which seeks to address the aforementioned issues with the four-step process using a post-processing technique incorporated through a feedback mechanism in the sequential four-step process.

The post-processing technique aims at improving the stability and convergence properties, thereby improving the reliability of the planning process. The core of the technique consists of an improved traffic assignment algorithm labeled Slope-Based Multi-Path Algorithm or SMPA developed by Kumar and Peeta (2010). In addition to the SMPA, the technique consists of perturbation assignment and O-D prioritization schemes. Perturbation assignment

provides a warm start and O-D prioritization catalyzes the rate of convergence. These techniques are discussed in more detail in the next section.

PROPOSED METHODOLOGY

The logic of the proposed methodology is illustrated by the conceptual flow chart in Figure 2. The feedback loop involving the post-processing technique terminates when the average of absolute percentage change in the link flows becomes less than a pre-specified threshold value. The sequence of steps of the post-processing technique is shown in the implementation flow chart in Figure 3.

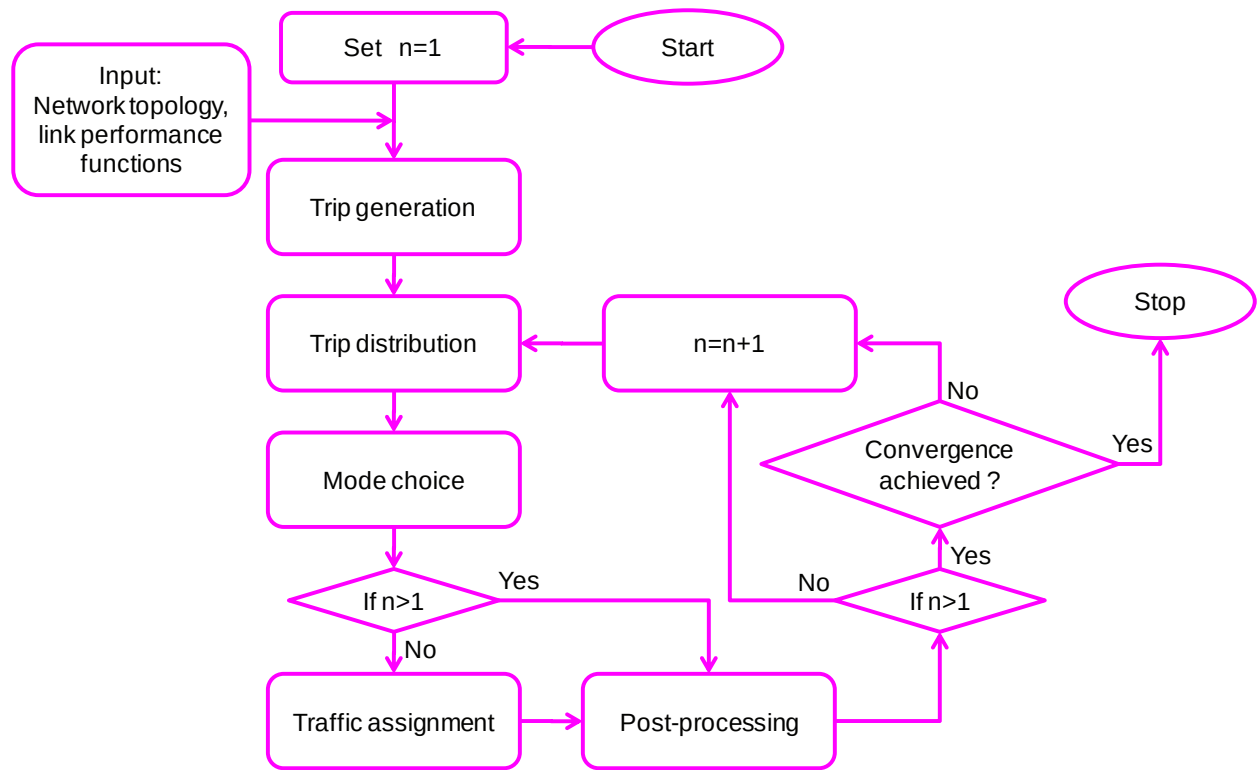


Figure 2: Conceptual flow chart of the post-processing technique using a feedback loop

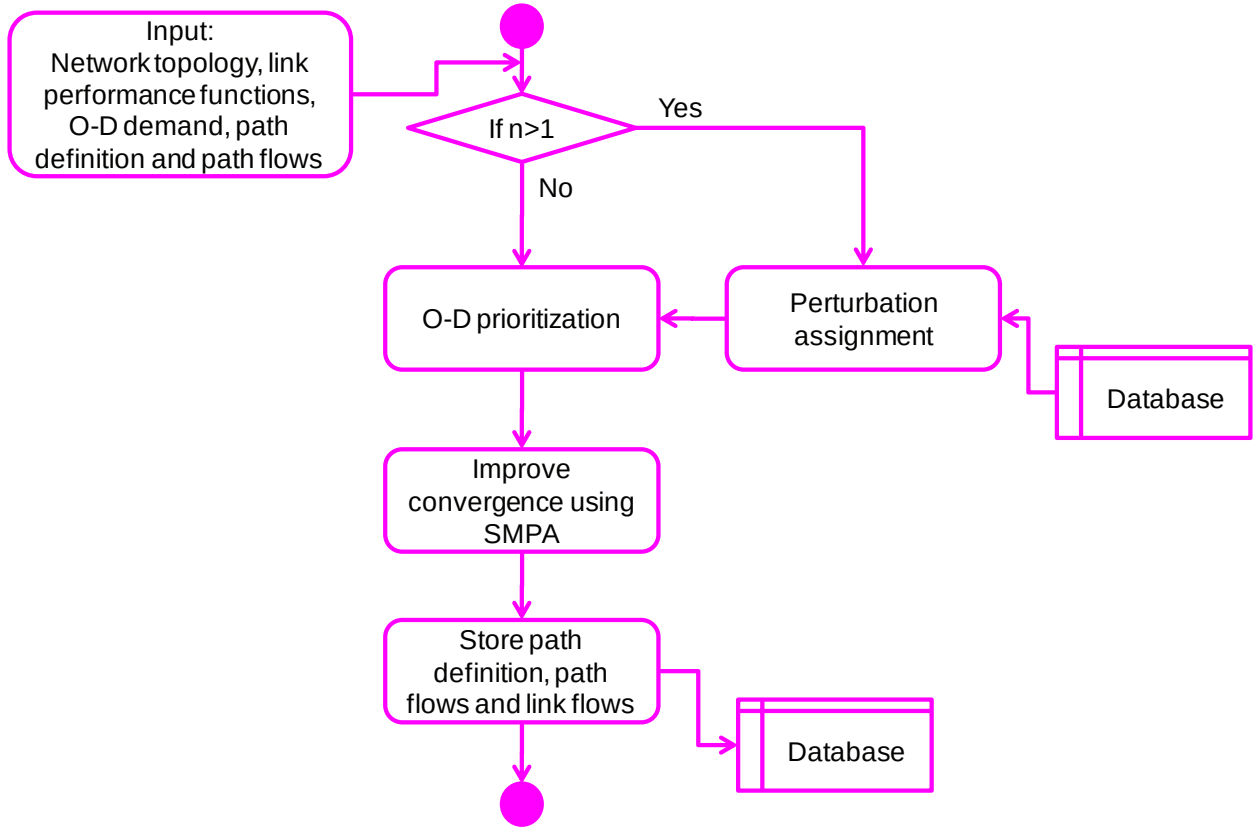


Figure 3: Implementation flow chart of the post-processing technique

As shown in Figure 3, there are three components for the post-processing technique: perturbation assignment, O-D prioritization, and the SMPA. The SMPA is the most important component of the post-processing technique. Hence, a brief review of this algorithm is provided first, and then the details of perturbation assignment and O-D prioritization are presented.

Review of the SMPA

The SMPA operates in the space of path flows, uses a sequential decomposition based O-D equilibration scheme, and updates all feasible paths of an O-D pair simultaneously. The novelty of this algorithm lies in two aspects of the flow update mechanism: (i) obviating the need for a line search in each iteration, and (ii) the way in which the sensitivity of path costs relative to flow, referred to as slopes, are used in the equilibration process. The SMPA algorithm consists of an inner loop which seeks the equilibration of an O-D pair and an outer loop that sequentially moves from one O-D pair to the next and checks the termination criteria after all of the O-D pairs are considered (for details, see Kumar and Peeta, 2010). The SMPA adopts the termination

criteria in terms of normalized gap (*Ngap*) or average excess cost (for details on *Ngap*, see Rose et al., 1988).

The sequential decomposition-based (one O-D at a time based) technique helps to achieve faster convergence per iteration, however it also introduces order bias in the solution. In addition, for larger networks, the gain in terms of a higher rate of convergence per iteration is traded-off by the computational time required for generating the shortest paths and updating the path set based on sequential approach. Hence, a hybrid version of the SMPA was developed in which shortest paths are generated and set of paths are updated for all the O-D pairs simultaneously, and then paths for each O-D pair are equilibrated and flows are updated based on the sequential approach. This novel approach reduces the order bias in the solution to a certain extent while reducing the computational time for convergence by a significant amount.

Perturbation assignment

Perturbation assignment is not a new concept and its importance has already been discussed in literature (for example, Kupsizewska and Vliet, 1998). A warm start using the perturbation assignment technique can drastically reduce the computational time for the assignment step in the four-step process involving the feedback loop. Hence, an implementation scheme for this technique suitable to feedback loop is developed in this study, as illustrated by the following pseudocode:

```

If old O-D demand=0
    If new O-D demand=0
        skip this O-D pair
    Else
        assign all demand to shortest path
    End if
Else
    new path flow =  $\left( \frac{\text{new O-D demand}}{\text{old O-D demand}} \right) * \text{old path flow}$ 
End if

```

O-D prioritization

The path-based algorithms equilibrate the O-D pair one-at-a-time in sequential order. The convergence characteristics of the algorithm will depend on the order in which the O-D pairs are equilibrated. The aim of O-D prioritization is to determine the order which enables the algorithm to achieve faster and stable convergence. Figure 4 shows the steps needed to identify the criteria for O-D prioritization. For a network, there can be multiple ways of O-D prioritization. Hence, there is the need to determine which criteria work the best for a given network. It is important to mention here that the best way of O-D prioritization can be different for different networks and different algorithms. The O-D prioritization process needs to be carried out only once for a given network.

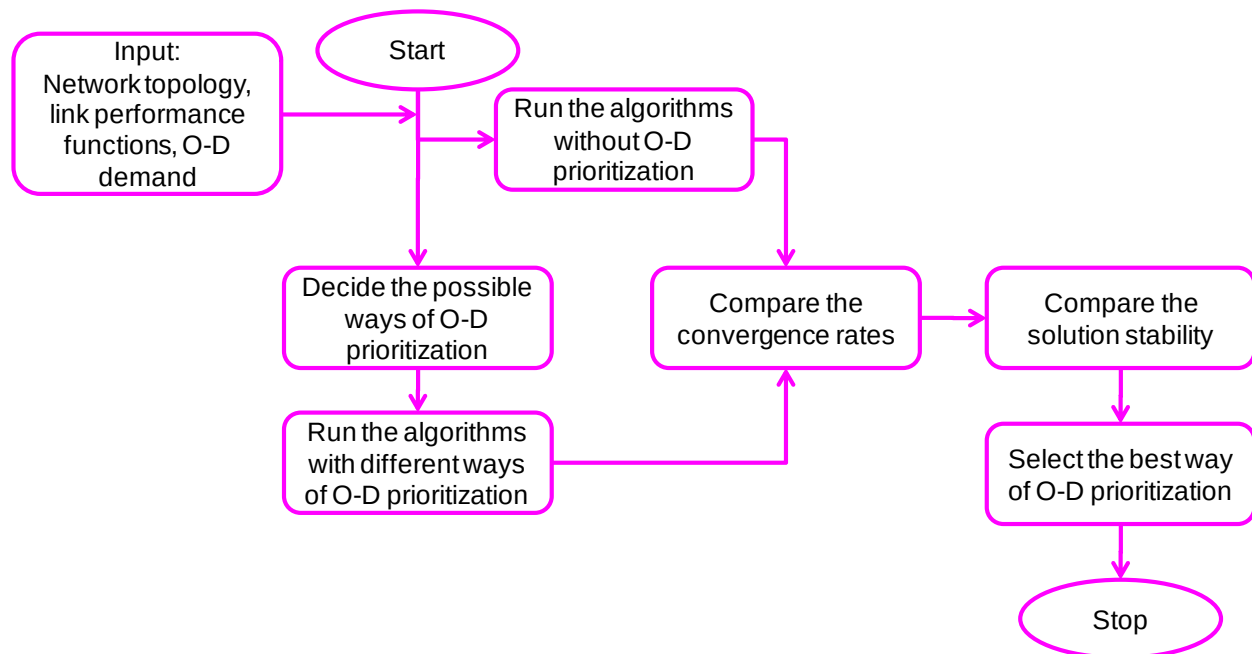


Figure 4: Deciding the criteria for O-D prioritization

In this study, three criteria are analyzed for O-D prioritization. O-D demands with higher values are likely to have a greater impact on traffic conditions compared to those with lower ones. Based on this, the first criterion for O-D prioritization can be generated as being represented by the ascending or descending order of O-D demand values. The second is the ascending or descending order of free flow travel time. Since O-D demands and travel times can

have meaningful impacts on the equilibration process, a third criterion is proposed by combining the first two criteria by assigning them relative weights.

COMPUTATIONAL RESULTS

Computational experiments are performed to test the effectiveness of the three components of the proposed post-processing technique. MATLAB is used as the computational platform and Sioux Falls, Anaheim and Borman Corridor networks are used as the study networks. Here, we illustrate the results for the Borman Corridor, as the trends are similar for the other two networks.

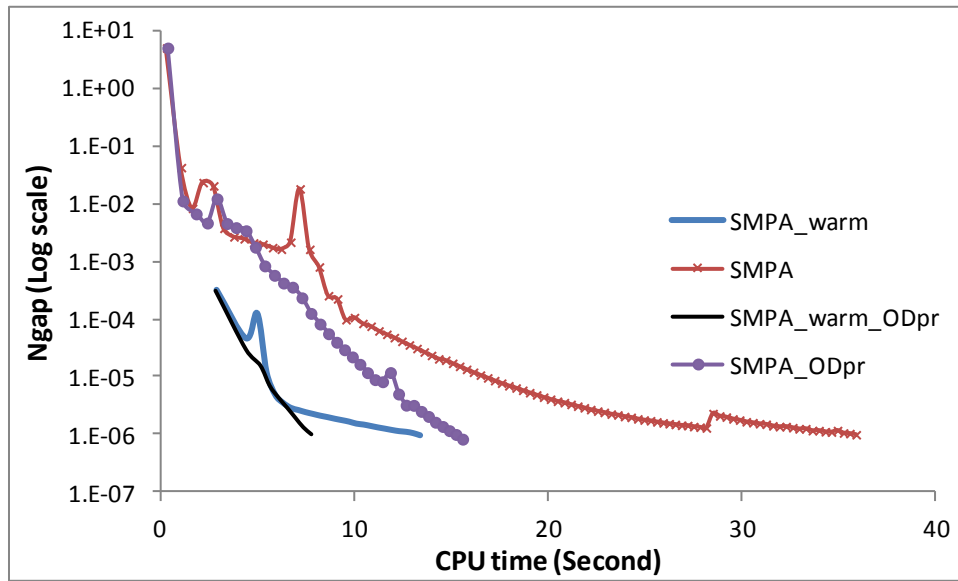


Figure 5: Convergence characteristics for Borman Corridor network

Figure 5 shows the results of the computational experiments for the Borman Corridor network. The ascending order combined criterion of O-D prioritization resulted in the least convergence time for this network. As shown in the figure, the O-D prioritized SMPA with warm start (labeled SMPA_warm_ODpr) performs better than the SMPA with warm start alone (labeled SMPA_warm), which in turn performs better than the O-D prioritized SMPA (labeled SMPA_ODpr). The O-D prioritized SMPA performs better than SMPA alone. The results suggest that link flows obtained through the O-D prioritized SMPA are more stable and approach equilibrium at earlier iterations.

IMPLICATIONS FOR PRACTICE

The study develops an enhanced travel demand modeling framework. The three components of the post-processing technique provide the ability to address key issues related to stability, consistency, and convergence. Results of computational experiments indicate that a warm start using perturbation assignment and the O-D prioritization component have significant benefits over the base case of cold start and non-prioritized implementation of traffic assignment algorithm. The proposed methodology improves the convergence characteristics of the assignment process as well as leads to a more stable solution with lesser noise.

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