Development and Calibration of a Long Distance Passenger Traffic Assignment Model

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ABSTRACT

This paper studies the assignment of long distance passenger traffic on a highway corridor network. First, we propose a traditional model for the long distance traffic assignment considering interactions with local commuter traffic. It addresses the effect of local sub-networks on highway corridors. An interactive algorithm is developed to solve for the exact solution. Then, to address the potential computational issues that arise therein, a decomposition method is proposed by introducing a new concept of corridor elasticity. An assignment procedure for long distance passenger traffic is developed accordingly. Numerical tests show that the proposed decomposition method makes significant improvements in computational performance at a small loss of optimality. This decomposition method well approximates the exact assignment from the traditional formulation, especially when the highway corridors are near-saturation. The proposed decomposition method appears practical for application.

Keywords: Long distance passenger travel, Bush-based traffic assignment, Capacity elasticity
1 INTRODUCTION

1.1 Background

The long distance travel is a common form of travel, typical to both business and leisure travelers. With the rapid development of technologies and the economy, people are increasingly active in long distance travel. The 1995 American Travel Survey stated that nearly 1 billion long distance (longer than 100 miles one way) person-trips were made by Americans, which accounted for 25% of all trip miles traveled (1). The 2001 National Household Travel Survey (NHTS) reported that about 2.6 billion long distance (longer than 50 miles one way) trips happened in the USA annually (2). The vast majority of long distance trips (nearly 90%) were made on highways, and the average length of long distance trips by private vehicles was 220 miles one-way (3). Therefore, it suggests that long distance passenger traffic has played an indispensable role in highway traffic study, and policy makers need more knowledge about long distance travel features on highway networks in a macroscopic perspective.

Prior studies on long distance travel include analysis on effects of socio-economic, demographic and geographic factors on long distance travel, the mode choices, and also the time-of-day choices for long distance trips (4, 5, 6, 7). Different from these studies, this paper focuses on modeling the assignment of long distance passenger traffic on a general transportation network, which remains yet to be carefully examined in the national traffic assignment framework. Most traffic assignment studies in the literature focus exclusively on local commuter traffic, in which commuters know roadway conditions well and repeat their travel every day, or long-haul freight flow assignment such as the U.S. Department of Transportation’s third generation Freight Analysis Framework (8). We find that our study problem deserves a separate exploration of its own right. How can long distance passenger traffic be assigned onto the roadway network featuring their special travel behavior, and also featuring a special structure of the national corridor network that interacts with local roadway traffic? The latter is significant when a corridor traverses a congested urban area such as the greater Chicago region. We develop methodologies and algorithms to assign long distance passenger traffic onto a transportation network that is expected to synchronize with local traffic assignment, by exploiting its unique network structure and travel behavior.

1.2 The Study Problem

Long distance passenger traffic assignment on a national network with such a tremendous size poses great challenges. It must consider interactions with local commuter traffic because of their shared right-of-way. Long distance passenger travels take place on major national corridors, on which local commuter traffic accounts for most of the total volume within a metropolitan area. Figure 1 illustrates a typical corridor network for long distance traffic. A shaded area associated with a corridor represents its local sub-network, which comprises of local paths parallel to the corridor. The local sub-networks are geographically isolated from each other, and are considered to have their own, independent local demand. In addition, long distance travelers only travel on corridors, while local commuters may travel on both local and corridor roads. We assume that the O-D demand of long distance travels on the corridor network and the local demand are both known. The research objective is to assign long distance travelers on the roadway network while considering their interaction with local commuters through shared right-of-way mainly on highway corridors in metropolitan areas.
Without considering interaction with local traffic, long distance traffic may be assigned onto a route to avoid an urban area. However, local traffic may have some flexibility in choosing their routes and getting off the corridors if the corridors are congested. In this sense, long distance travelers may be able to squeeze off the local travelers and get more capacity from the corridors. Therefore, this interactive effect of local traffic is important to long distance travelers.

A straightforward way to consider this interactive behavior is to propose a traditional model for a large-scale, integrated traffic assignment for both the local and long distance travelers simultaneously, which is technically challenging because of the network size and the overwhelming demand for data. In this paper, we propose a decomposition method and a concept of elasticity coefficient to approximately capture this interactive effect between local and long distance travelers.

The remainder of this paper is organized as follows. Section 2 performs thorough analysis on long distance passenger travel, in terms of basic travel features and network characteristic on which they usually travel. Section 3 formulates a traditional model of long distance traffic assignment and proposes an interactive algorithm. Section 4 describes a decomposition method that introduces concept of corridor elasticity and defines a capacity elasticity coefficient for highway corridor. Section 5 provides numerical tests to compare the optimal results from the traditional formulation with the approximate results using the decomposition method. Their computational performances are also tested. Section 6 presents conclusions.

2 ANALYSIS OF LONG DISTANCE PASSENGER TRAVEL

2.1 Characteristics of Long Distance Passenger Travel

Long distance travelers exhibit different travel behaviors, compared to local commuter travelers. For example, long distance travelers, when going through a highway corridor in a congested metropolitan area, do not necessarily know the local alternative routes as local commuters do. Therefore, their choice of routes through major metropolitan areas appears more rigid than local travelers.
In addition, long distance passenger traffic shares many similar features as long-haul freight traffic when being assigned onto a major highway network. They both generally take major corridors around/through urban areas rather than get onto local non-arterial roadways. This may be partially explained that long distance passengers are not familiar with local roads. As a result, they are not as sensitive to corridors’ level of service as local commuters. On the other hand, truck drivers’ choice of routes is greatly constrained by availability of truck parking space, weight and size regulations on highways and between states. In this respect, long distance passengers have relatively more flexibility than long-haul truckers in terms of route choice.

2.2 Elasticity for a Through Corridor

Now we turn our attention to major corridors that accommodate long distance passenger traffic. Assume that a number of long distance travelers traversing a metropolitan area via a through corridor may add to traffic congestion on the corridor. In other words, the corridor is near-saturation and that additional traffic will ‘force’ local traffic off the arterial onto its surrounding local sub-network, making room for long distance traffic, -- an elastic characteristic of a corridor capacity to through traffic. If local traffic is sensitive to congestion and if enough alternative routes are available, local traffic may be easily squeezed off the corridors onto those alternative routes.

This elastic characteristic of corridor capacity relates to the configuration of its local sub-network. For instance, a freeway corridor with parallel frontage roads is common in states such as Texas. The elastic characteristic of such a corridor is explicit, since the parallel frontage roads provide convenient access to freeway and serve as an additional capacity when needed. Another extreme case is a major corridor without or with sparse access to parallel local roads, which often occurs in rural areas with sparse population. Travelers may have to drive a long distance (e.g. 3-5 miles) to access alternative parallel roads or there is even no parallel road to accommodate the local traffic diverted from the corridor, thus we regard it as an inelastic corridor.

As for a corridor with closely spaced access to parallel local roads, this configuration commonly exists in urban areas with densely spaced networks. Since the local roads are usually loaded with a certain volume of traffic and have limited capacity, their remaining capacity to accommodate additional traffic ‘squeezed off’ from highway corridors is rather limited. We need a numerical means to analyze the capacity elasticity of such corridors.

2.3 Definition of Corridor Elasticity

The measure of corridor elasticity is defined as follows. Considering a basic corridor segment associated with a local sub-network, we define the corridor performance function in terms of both local traffic and long distance through traffic on corridor: \( t(X, Y) \), where \( X \) denotes the local traffic on the corridor, and \( Y \) denotes the long distance traffic passing through the corridor. The function \( t(X, Y) \) is similar to the Bureau of Public Roads (BPR) function used in traffic engineering, except for two parameters to differentiate the local traffic from long distance through traffic.

To measure the additional capacity that may be ‘squeezed’ out for long distance traffic from the local traffic on the arterial corridor, we define the corridor capacity elasticity \( \rho \), conditioning on through traffic \( Y \) as:

\[
\rho|Y = \frac{X_0 - X}{X_0}
\]
Where $X_0$ is the local traffic on corridor when through traffic is zero, and $X$ is the local traffic on corridor with through traffic $Y$ imposed.

Figure 2 demonstrates the computation of corridor elasticity. Two parallel roadways connect nodes A and B. No entrance or exit of traffic is allowed between the two ends. The top road is designated as a corridor, and the bottom one as a local road. The BPR functions for the two roads are specified. The total local traffic demand from A to B is 600 units. Without any long distance through traffic, we calculate that at equilibrium, the local traffic on corridor $X_{cor}=568$ and the local traffic on local road $X_{loc}=32$. Suppose the long distance through traffic $Y$ ranging from 0 to 300 is ‘designated’ onto the corridor, the corridor elasticity $\rho$ with respect to through traffic $Y$ is calculated and displayed. We can see that with increase of through traffic $Y$ imposed on the corridor road, more local demand would switch onto the local road and the corridor elasticity increases accordingly.

The definition of corridor elasticity clearly reflects the connectivity between a corridor segment and its associated local sub-network. However, with a wide range of $Y$, to compute the corresponding elasticity values for corridor seems rather burdensome, and unnecessary for the practical applications. We are particularly interested in a critical capacity elasticity coefficient in order to approximate all the varying demand situations for a realistic corridor. The further investigation will be detailed in Section 4.

3 MODELING LONG DISTANCE TRAFFIC ASSIGNMENT ON A CORRIDOR NETWORK

This section proposes a model for long distance passenger traffic assignment on a corridor network, addressing the effect of local sub-networks on elastic corridors simultaneously. An interactive algorithm is developed to solve for the exact solution.

3.1 Overview of Traffic Assignment Techniques

There is a large body of literature on traffic assignment techniques, which often target at networks within metropolitan planning organization (MPO) regions. In this section, we briefly review the relevant literature in conventional traffic assignment.

The conventional static traffic assignment models have been widely used to aid policy and project decision making for agencies. Their widely recognized advantages include the
capability to solve large-scale problems, convergence to precise equilibriums, and consistency of solutions from varying appropriate algorithms (9). The traffic assignment techniques have been substantially developed, which is exemplified by the Convex Combination (Frank-Wolfe) method (10). This method has been considered as a standard solver of traffic assignment problem for over a quarter century.

Exploration on efficient solution algorithms for the static user equilibrium (UE) traffic assignment problem is still one of the most concerned subjects in transportation research (11). The continuous enthusiasm for the UE problem (12, 13) was motivated by the inadequacy of existing algorithms to address large-scale realistic applications. It was shown that the Frank-Wolfe algorithm was unable to obtain an equilibrium solution precise enough for basic planning purposes (14). The bush-based algorithms (15, 16, 17) were proposed and further explored for traffic assignment problems based on the concept of bush (18), which represented an acyclic network rooted at an origin. In general, compared with link-based or route-based counterparts, the bush-based algorithms were found to be more efficient due to the modest computation time to produce highly precise UE solutions, but the performance of algorithms might be distorted by a number of implementation factors (19).

### 3.2 Formulation

Notations:

- $A$: set of inelastic corridor arcs; $a \in A$
- $W$: set of elastic corridor arcs; $w \in W$
- $L_w$: set of local arcs on the sub-network around elastic corridor arc $w$; $l \in L_w$
- $K_{rs}$: set of corridor paths connecting O-D pair $r$-$s$; $k \in K_{rs}$
- $P_w$: set of local paths as alternatives of elastic corridor arc $w$; $p \in P_w$
- $x_a$: long distance through traffic flow on inelastic corridor arc $a$
- $y_l$: local traffic flow on local arc $l$
- $t_l$: travel time on local arc $l$
- $z_w$: total traffic flow on elastic corridor arc $w$
- $t_w$: travel time on elastic corridor arc $w$
- $f_k^{rs}$: long distance through traffic flow on corridor path $k$ connecting O-D pair $r$-$s$
- $g_p^w$: local traffic flow on local path $p$ as alternative of elastic corridor arc $w$
- $q_{rs}$: long distance through traffic demand between origin $r$ and destination $s$
- $d_w$: local traffic demand along elastic corridor arc $w$
- $\delta_{a,k}$: indicator variable, 1 if arc $a$ is on corridor path $k$ between O-D pair $r$-$s$, 0 otherwise
- $\eta_{l,p}$: indicator variable, 1 if arc $l$ is on local path $p$, 0 otherwise

To formulate the long distance traffic assignment problem, we classify the links (or, arcs) on the study network into three categories: inelastic corridor arcs, elastic corridor arcs, and local arcs. Inelastic arcs are the ones without parallel capacity on local area so that local traffic cannot switch off the corridor in spite of corridor congestion. Here, each local sub-network being modeled corresponds to one elastic corridor arc, and that corridor arc represents a through route to allow long distance traffic to traverse the local area. Local arcs on a local sub-network comprise the parallel local paths for the corresponding elastic corridor arc.

The objective is to assign long distance travelers considering their interaction with local commuters through shared right-of-way on corridors. Since they have distinct route choice
behaviors (long distance traffic travel on corridors, while local commuters do on both local and corridor roads depending on traffic situations), we regard them as distinct categories of homogeneous travelers. Both local commuters and long distance travelers follow the user equilibrium principle. One way of solution would be to model the entire network of relevant roadways in the traditional way of network traffic assignment. Referring to the classical Beckmann’s formulation, we propose a model as below.

\[ \text{Min } \sum_{a \in A} t_a(u) du + \sum_{w \in W} \int_{0}^{z_w} t_w(u) du + \sum_{w \in W} \sum_{l \in l_w} \int_{0}^{y_l} t_l(u) du \]

\[ s.t. \quad \sum_{k} f_{k}^{rs} = q_{rs}, \quad \forall r, s \]

\[ \sum_{p} g_{p}^{w} = d_{w}, \quad \forall w \in W \]

\[ x_a = \sum_{rs} \sum_{k} f_{k}^{rs} \cdot \delta_{a,k}, \quad \forall a \in A \]

\[ y_l = \sum_{p} g_{p}^{w} \cdot \eta_{l,p}, \quad \forall w \in W, \forall l \in l_w \]

\[ z_w = \sum_{rs} \sum_{k} f_{k}^{rs} \cdot \delta_{w,k} + \sum_{p} g_{p}^{w} \cdot \eta_{w,p}, \quad \forall w \in W \]

\[ f_{k}^{rs} \geq 0, \quad g_{p}^{w} \geq 0 \]

The objective function (1) is the sum of integrals of travel cost functions for all categories of arcs on the corridor network. The first term accounts for the travel time on inelastic corridor arcs \( t_a \) with respect to only long distance traffic. The local traffic volumes on them are treated as constants. The second term accounts for the travel time on elastic corridor arcs \( t_w \), which is formulated in regard to the sum of long distance traffic and the varying local traffic volume on them. And the third term accounts for the travel time on local arcs \( t_l \) with respect to only local traffic volumes on them. All the travel cost functions are assumed to be increasing and positive.

The constraint (2) represents the long distance traffic demand restrictions for OD pairs on corridor network, and constraint (3) represents the local traffic demand restrictions along each elastic corridor arc with its associated local sub-network. The constraints (4) through (6) represent arc flow conservations. Then, we can prove that the first-order conditions for this minimization program are identical to the traffic assignment equilibrium conditions. The Lagrangian with respect to the equality constraint is:

\[ L(f, g, v) = Z + \sum_{rs} v_{rs} \left( q_{rs} - \sum_{k} f_{k}^{rs} \right) + \sum_{w \in W} v_{w} \left( d_{w} - \sum_{p} g_{p}^{w} \right) \]
Where $v_{rs}$ denotes the dual variable associated with the corridor path flow conservation, and $v_{w}$ denotes the dual variable associated with the local path flow conservation. At the stationary point of the Lagrangian, the following conditions have to hold with respect to the path-flow variables:

$$f_{k}^r \frac{\partial L(f, g, v)}{\partial f_{k}^r} = 0 \text{ and } \frac{\partial L(f, g, v)}{\partial f_{k}^r} \geq 0$$

$$g_{p}^w \frac{\partial L(f, g, v)}{\partial g_{p}^w} = 0 \text{ and } \frac{\partial L(f, g, v)}{\partial g_{p}^w} \geq 0$$

Equivalently, we get:

$$\frac{\partial L(f, g, v)}{\partial f_{k}^r} = \sum_{a \in A} t_{a}(x_{a}) \cdot \delta_{a,k}^r + \sum_{w \in W} t_{w}(z_{w}) \cdot \delta_{w,k}^r - v_{rs} = c_{k} - v_{rs} \geq 0$$

$$\frac{\partial L(f, g, v)}{\partial g_{p}^w} = \sum_{l \in L_{w}} t_{l}(y_{l}) \cdot \eta_{l,p} + t_{w}(z_{w}) \cdot \eta_{w,p} - v_{w} = c_{p} - v_{w} \geq 0$$

Where $c_{k}$ is the total travel time on corridor path $k$, and $c_{p}$ is the total travel time on local path $p$.

Now, the first-order conditions are summarized as:

$$f_{k}^r \cdot (c_{k} - v_{rs}) = 0$$

$$c_{k} - v_{rs} \geq 0$$

$$g_{p}^w \cdot (c_{p} - v_{w}) = 0$$

$$c_{p} - v_{w} \geq 0$$

$$\sum_{k} f_{k}^rs = q_{rs}$$

$$\sum_{p} g_{p}^w = d_{w}$$

Therefore, the Lagrange multiplier $v_{rs}$ equals the minimum corridor path travel time between origin $r$ and destination $s$, and $v_{w}$ equals the minimum path travel time within the local sub-network associated with corridor arc $w$. Referring to the proof of classical static traffic assignment problem (9), it is easy to prove that the objective function $Z$ is strictly convex since its Hessian is positive definite. Thus the proposed formulation has a unique minimum, which is the equilibrium solution of this long distance traffic assignment problem.

### 3.3 Interactive Assignment Algorithm

In our formulation, long distance travelers and local commuters can be regarded as two categories of homogeneous travelers. An interactive algorithm is designed accordingly to solve it. The key point here is to assign one category of homogeneous travelers (long distance travelers or local commuters) each time, and then use the resulting outcome to update the assignment of the other category.

As illustrated in Figure 3, the complete corridor network consists of corridors and a set of local sub-networks associated with elastic corridor arcs. The framework of solution is as follows.

1. Conduct long distance traffic assignment on corridors, regarding the current local traffic imposed on elastic corridor arcs as constants.

2. Readjust local traffic assignment within each local sub-network associated with one elastic corridor arc, based on the updated corridor travel time resulting from prior long distance traffic assignment.
3. Repeat Step 1 till convergences for both long distance traffic on corridors and local traffic on each local sub-network.

![Diagram](Conventional traffic assignment technique Updated long distance traffic imposed on elastic corridor arcs Corridors Local sub-networks Updated local traffic imposed on elastic corridor arcs)

**FIGURE 3** Interactive process of traffic assignment on original network.

The logic of this interactive algorithm is easy to understand. We aim to achieve the user equilibrium for both long distance traffic on corridors and local traffic on each local sub-network. The existing conventional traffic assignment techniques can be adopted for the convenience of implementation.

However, computational issues may arise when addressing a large-scale realistic network with numerous local sub-networks simultaneously. Because of the size of such a network, it is technically impossible to conduct traffic assignment on a complete national network. To reduce computational complexity, a corridor network only for long distance traffic is extracted, with a means to account for interaction with local commuter traffic on the local roads. Such interaction is captured through the calculation of capacity elasticity on corridor in a local area, as introduced in Section 2. This is somehow equivalent to network decomposition, making sub-networks and sub-problems that are computationally easier to solve. We will develop a decomposition method in the next section.

### 4 DECOMPOSITION METHOD FOR LONG DISTANCE TRAFFIC ASSIGNMENT

The original, complete corridor network is decomposable into corridors and separate local sub-networks by introducing capacity elasticity coefficient for corridor. The corridor elasticity concept allows dealing with corridor network directly, without a need for incorporating local sub-networks. It greatly simplifies the entire network and computational complexity.

#### 4.1 Capacity Elasticity Coefficient

The definition of corridor elasticity was already specified in Section 2. We notice that in practice, usually the long distance passenger traffic imposed on a corridor is relatively small (especially compared to the normal capacity value of corridor), and the resulting corridor elasticity at low local traffic would not be substantial. This is because at light or medium traffic, a major corridor is always faster than lower-class local roads, in which case, analysis of capacity elasticity becomes meaningless. The significance of the concept of elasticity resides in those corridors with relatively high volume, or near-saturated local traffic. Therefore, we further investigate the corridor elasticity in near-saturation conditions here.
Under near-saturation conditions of a corridor, the maximum ratio of shifted local traffic from the corridor onto its surrounding local sub-network is an effective measure of capacity elasticity/flexibility. We define this critical ratio as the capacity elasticity coefficient. Therefore, a corridor arc has its elastic capacity defined as the sum of its normal capacity value (e.g. original capacity value used in its BPR function) and the extended capacity because of an elasticity coefficient. The basic idea of applying this elasticity coefficient to a corridor arc is that we can conclude the corridor arc is still uncongested when the total traffic on it approaches the normal capacity and remains within its elastic capacity. It tells how much additional capacity to the existing traffic condition would be available for long distance traffic. In this way, we do not intend to examine a large spectrum of $Y$ values (long distance traffic volumes passing through the corridor) to obtain the corresponding corridor elasticity as did in section 2.3. Instead, we use one single coefficient for elasticity in the most concerned near-saturated situations for long distance travelers. The interaction with local roads is approximated by developing a critical elasticity coefficient.

### 4.2 Calibration Method

A calibration procedure is proposed here to calibrate the capacity elasticity coefficient for each corridor arc. This procedure requires calculating local traffic volumes shifted onto alternative local paths at equilibrium.

**Step 1:** Calculate the travel time $T$ on the corridor arc of interest with total traffic imposed equivalent to its normal capacity (i.e. this corridor arc happens to be saturated as a result).

**Step 2:** Identify all the local paths as alternatives of this corridor arc within its associated local sub-network. Find out those local paths with initial travel time less than $T$, and then calculate the extra local traffic volume that needs to be imposed on each of them so as to reach the travel time $T$ respectively.

**Step 3:** Sum up all the extra local traffic flows obtained from Step 2, and divide it by the normal capacity value of the studied corridor arc (this ratio is the calibrated value of its capacity elasticity coefficient).

It is noted that the computed capacity elasticity coefficient for a corridor in this way can be treated as the maximum capacity elasticity to accommodate extra through traffic without incurring congestion on corridor. It would serve as a bound to measure the corridor flexibility under near-saturation conditions.

### 4.3 Network Assignment Procedure

To solve the original traffic assignment problem approximately, now we incorporate capacity elasticity coefficients for the major corridor arcs on a simplified corridor network. The assignment procedure is elaborated below:

**Step 1:** OD data preparation for long distance traffic, and the network file of corridors pre-loaded with current local traffic volume.
Step 2: Conduct traffic assignment of the long distance traffic on the corridors. The initial equilibrium solutions are obtained. This assignment assumes a constant local traffic on corridors as input in Step 1.

Step 3: Check each elastic corridor arc on which the resulting traffic volume exceeds its normal capacity.

If the traffic is still within the range of elastic capacity, then we reduce the total arc volume to its normal capacity, which is equivalent to ‘forcing’ off some local traffic onto the surrounding local sub-network to avoid the additional congestion; otherwise (the traffic volume exceeds the elastic capacity), additional delay would have to be added by applying the extra traffic volume to arc’s BPR function.

Update the solutions (i.e. arc flows and associated arc costs) on the corridor network accordingly. Check if the equilibrium still holds for the updated solutions subject to a criterion of convergence. If yes, go to Step 4; otherwise go to Step 2.

Step 4: Terminate the algorithm.

The flowchart is illustrated in Figure 4, where the bush-based traffic assignment technique is applied in Step 2 as an example.

4.4 Summary and Remarks

With the introduction of capacity elasticity coefficients for major corridors, we are able to decompose a large national network that includes both local roads and through corridors into one of corridors in the role of the Master problem and ones of local roads in the role of sub-problems. The concept of corridor capacity elasticity allows interaction between the ‘Master problem’ and ‘sub-problems’. This capacity elasticity coefficient enables the consideration of local traffic to a reasonable extent.

The calibration of capacity elasticity coefficient for a corridor is effective by identifying its critical elastic capacity to accommodate long distance traffic, which is in accordance with the fact that long distance travelers always try to avoid congestion. It appears that the simplified corridor network can provide a good approximation analytically to the original complete network, especially when the corridor arcs are near-saturated.

Just as other practical applications, this research is not free of issues and concerns. These issues typically include: (1) It is difficult to come up with the travel cost functions for those lower-class local roads; (2) The local sub-network could be rather complex yet important to the corridor congestion. In addition, how to effectively measure the congested travel time on a corridor segment when total traffic exceeds its elastic capacity remains a big challenge. The simple application of BPR function may be inappropriate. The adjustment based on empirical study of congested travel time would be necessary on realistic corridors.

In short, the proposed decomposition method attempts to balance between the computational complexity and solution quality.
5 EXPERIMENTAL RESULTS

We design numerical experiments to compare the long distance traffic assignment on an original complete network using traditional method, to the assignment using decomposition method that incorporates capacity elasticity coefficients. The experimental results are organized into two subsections. The first subsection demonstrates their gaps through a simple test network. The second subsection extends to a large Chicago network in order to test the computational performances of these two methods.

5.1 Tests on a Simple Network
As illustrated in the left part of Figure 5, a simple network consists of 9 nodes, 24 corridor arcs, and one shaded area for a local sub-network that shares elastic corridor arc (4,7) or (7,4). Two

FIGURE 4 Flowchart of new assignment procedure.
local routes depicted as dashed lines along corridor arc (4,7) or (7,4) within this local sub-
network are specified in the right part of Figure 5.

FIGURE 5 A simple test network.

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<td>(9,6)</td>
<td>6</td>
<td>1100</td>
<td>2000</td>
</tr>
<tr>
<td>24</td>
<td>(9,8)</td>
<td>4</td>
<td>1500</td>
<td>2000</td>
</tr>
</tbody>
</table>

FIGURE 6 Basic input for test network.
For simplicity, each corridor arc uses a standard BPR function. To differentiate from the corridor arcs, linear travel cost functions with respect to local traffic are applied to local arcs 1 and 2. Following the calibration method described in Section 4, it is easy to get the capacity elasticity coefficient equal to 0.2 for corridor arc (4,7) or (7,4). The parameters for arcs and the randomly generated long distance traffic OD demands are shown in Figure 6 as the basic input. All the numerical tests in this section are conducted on a Windows 7 x64 Workstation with two 2.70 GHz CPUs and 4 GB RAM, and we code algorithms in C programming language. The convergence gap in the coded algorithm for each method is set to be 1e-4.

We test different cases with long distance travel demand from origin node 1 to destination node 9 varying from 0 to 1000 with an increment of 100 units. First we compute the traffic assignment results on the original, complete network. It is found that at equilibrium, the used corridor arc (4,7) are near-saturated when the long distance demand is approximately within the range from 500 to 700 units, and the congestion on arc (4,7) would occur when this demand exceeds 700 units. In comparison, we also compute the long distance traffic assignment results for each case by decomposing the network and using the calibrated elasticity coefficients. In general, their assignment results are close. For each case, we compute the percentage of total deviations of long distance traffic on corridor arcs between the two methods with varying long distance demand, as displayed in Figure 7.

It is shown that the decomposition method has good approximation to the exact assignment based on the original, complete network. The deviation of approximation is always within 4%. Note that the two assignments from the proposed decomposition and the traditional methods are identical when the OD demand from node 1 to node 9 is zero. And the deviation gradually increases until the elastic corridor arc (4,7) approaches the near-saturation situations. It should be noted that the decomposition method provides particularly close results when dealing with the near-saturation situation with the long distance demand from 600 to 700 units (within 1% deviation). This finding supports our proposed method of decomposition using capacity elasticity. In addition, the error of the assignment tends to increase with congestion on the elastic corridor arc (4,7), which implies that adjustment of capacity elasticity is needed to reflect the right level of congestion in order to fine tune the results.

FIGURE 7 Deviation percentages with varying OD demand.
5.2 Computational Tests on the Chicago Network

We conduct further tests on a large Chicago sketch network, which comprises of 933 nodes, 387 zones and 2950 arcs. This network, developed by the Chicago Area Transportation Study, is a realistic yet aggregated representation of the Chicago region as shown in Figure 8. The original data files were released to the public by Bar-Gera (20). The purpose of our tests here is to compare the computational performances of the two methods to showcase the significant computational advantage of our proposed decomposition method. In this test, we treat all the arcs in the Chicago sketch network as corridor arcs and randomly select a number of them as elastic ones with their local sub-networks incorporated. The original OD data are used as long distance passenger traffic data here, and the local traffic demand on each corridor arc is randomly generated as 50-70% of its normal capacity value. Each local sub-network is simply assumed to contain two parallel local roads and the calibrated elasticity coefficient is between 0 and 1. This hypothetical local sub-network information can be adjusted to be consistent with any realistic condition, discussion of which is beyond the scope of this study. We observe that the data on this Chicago sketch network provides low levels of congestion (only about 10% arcs are congested, and among which the average volume over capacity (v/c) ratio is about 1.2). Therefore, the advantage of applying capacity elasticity coefficients is obvious.

We test different cases with varying number of elastic corridor arcs selected. Two methods are applied to each case respectively. The computational times until convergence are compared. We find that with the increase of number of randomly selected elastic arcs (more local sub-networks incorporated accordingly), the computational time for the original, complete network drastically increases. As in Figure 9, the computational time increases from within 50 seconds for 30 or less local sub-networks to nearly 620 seconds for over 60 local sub-networks.
In an extreme case, the computational time of the traditional method exceeds a predetermined
time limit of 20 minutes for the case of 80 local sub-networks. This exponential trend
demonstrates the poor computational performance of the traditional method based on the
original, complete network. In contrast, the decomposition method always converges within only
30 seconds, even for the extreme case of 80 local sub-networks.

![Computational performances for two methods.](image)

**FIGURE 9** Computational performances for two methods.

Importantly, the proposed decomposition method maintains a quality solution in this test.
The resulting assignment differences between these two methods are always within 2%. It
appears that the small loss of optimality is well worth the significant improvement in
computational performance. The numerical tests again validate the efficiency of the proposed
method on a decomposed corridor network.

6. CONCLUSIONS

Long distance passenger traffic assignment is an area that remains yet to be carefully examined
in the national traffic assignment framework. This paper aims to develop appropriate models and
algorithms to assign long distance passenger traffic onto a national transportation network, by
comprehensively considering the existing traffic assignment techniques as well as the effect of
local commuters.

A traditional model for the assignment of long distance passenger traffic on a corridor
network is proposed, which is integrated with local traffic assignment. Because of the
computational challenge from the large-size realistic network that has numerous local sub-
networks, we propose a decomposition method by introducing a new concept of corridor
elasticity. In this way, the effect from the local sub-networks on corridors is approximated by the
capacity elasticity coefficients. Therefore, the computational complexity is significantly reduced.

The numerical tests show small loss of optimality but great improvement to the
computational time by applying the capacity elasticity concept to long distance traffic
assignment. This decomposition method well approximates the exact assignment from the traditional formulation, especially when the corridor arcs are near-saturation. The method is numerically proved promising for future practical applications to various highway corridor networks. An encouraging advantage of using the capacity elasticity coefficient is that calibration of the coefficients is independent between local areas, and can be theoretically done by using traditional traffic assignment to a local area and can also be approached through using approximate local sub-network and local demand.

As a remaining work in the future, a thorough empirical calibration of capacity elasticity coefficients for various realistic network structures are needed. How to appropriately adjust the congested travel time is also worth further efforts in order for better approximations.

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