Forecasting Network Traffic for Small Communities in Utah

Anthony Chen, Sarawut Jansuwan, and Seungkyu Ryu

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FORECASTING NETWORK TRAFFIC FOR SMALL COMMUNITIES IN UTAH

Prepared For:

Utah Transportation Center

Authored By:

Anthony Chen

Sarawut Jansuwan

Seungkyu Ryu

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Current practice in modeling network traffic for planning applications is through a four-step travel demand forecasting model (i.e., trip generation, trip distribution, mode choice, and traffic assignment) that requires travel surveys and specialized technical staffs to operate. Although such a modeling approach has been used in practice in major metropolitan planning organizations (MPOs), many small MPOs usually do not have sufficient resources to conduct travel surveys, nor to house technical staffs for model development and maintenance. The purpose of this paper is to develop a simplified planning tool specifically targeted at small MPOs. To show proof of concept, a case study is conducted using a small MPO in Utah to demonstrate how the tool can be implemented in practice.</td></tr>
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Executive Summary

Transportation planning plays a fundamental role in supporting the economic, social and environmental goals for cities and regions all around the nation. Because of this importance, federal regulations in the United States require each urbanized area over 50,000 populations to have a Metropolitan Planning Organization (MPO) responsible for transportation planning. Current practice of MPOs in modeling network traffic is through a four-step travel demand forecasting model (i.e., trip generation, trip distribution, mode choice, and traffic assignment) that requires travel surveys, travel demand estimation, calibration, validation, and forecasting processes. It requires specialized technical staffs to operate and maintain these models in order to use them to evaluate transportation improvement programs.

The purpose of this paper is to further develop this simplified planning tool for planning applications in small MPOs where resources hinder the development and applications of a full four-step travel demand forecasting model. Specifically, the simplified planning was developed based on the concept of Path Flow Estimator (PFE). It includes two modules: (a) a base year PFE for estimating and calibrating the origin-destination (O-D) trip table using current traffic counts, target O-D trip table, and trip production and trip attraction as constraints, and (b) a future year PFE for predicting network traffic conditions using future trip production and trip attraction and scaled baseline (calibrated) O-D trip table to match future total demand as constraints. To demonstrate the procedure, the study adopts Cache County MPO, a small-sized MPO in Utah, as a case study. For base year, the results of link flow estimates matched observed data within satisfactory error bounds. In addition, the results also showed satisfactory spatial distribution of trip makings when the estimation was constrained on both traffic counts and trip production and attraction flows. For future year, results are promising and applicable for evaluating impacts of transportation improvement projects.

1. Introduction

Transportation planning plays a fundamental role in supporting the economic, social and environmental goals for cities and regions all around the nation. Because of this importance, federal regulations in the United States require each urbanized area over 50,000 populations to have a Metropolitan Planning Organization (MPO) responsible for transportation planning (Meyer and Miller, 2001). One of the major functions of MPO is to develop and continuously pursue an appropriate analytical program to evaluate transportation alternatives and support metropolitan decision making, scaled to the size and complexity of the region and to the nature of its transportation issues and the realistically available options. The United States Department of Transportation (USDOT) relies on the MPO to ensure that highway and transit projects using federal funds are products of a credible planning process and meet local priorities. Current practice of MPOs in modeling network traffic is through a four-step travel demand forecasting model (i.e., trip generation, trip distribution, mode choice, and traffic assignment) that requires travel surveys, travel demand estimation, calibration, validation, and forecasting processes. It requires specialized technical staffs to operate and maintain these models in order to use them to evaluate transportation improvement programs.

According to the survey by Spielberg and Shapiro (2007), there are 205 small-sized (i.e., population range less than 200,000), 133 medium-sized (i.e., population range between 200,000 and 1,000,000), and 43 large-sized MPOs (i.e., population range greater than 1,000,000) nationwide. The survey results indicated that 144 out of 381 MPOs (about 38%) do not have or only have a small program on travel demand forecasting model. Yan (1998) added that many small and medium-sized areas usually do not have sufficient resources to conduct travel surveys, nor to house technical staffs for model development and maintenance. Because of this shortcoming, many small MPOs (i.e., about 46%) have to rely on the state transportation agency for implementing the modeling work. Schutz (2000) suggests that for these communities to meet the planning requirements, development of innovative methodologies is urgent and necessary.

Lee *et al*. (2006) provided an initial attempt to adapt the path flow estimator (PFE) as an alternative planning tool to model and forecast network traffic for planning applications in small communities (typically with a population less than 10,000). Preliminary results implemented in a small community in the City of St. Helena (the famous wine-producing region of Napa Valley in California with a population of 6,000) were promising. The purpose of this paper is to further develop this simplified PFE planning tool for planning applications in small MPOs where resources hinder the development and applications of a full four-step travel demand forecasting model. Specifically, the simplified PFE planning tool includes two modules: (a) a base year PFE for estimating and calibrating the origin-destination (O-D) trip table using current traffic counts, target trip table, and trip production and trip attraction as constraints, and (b) a future year PFE for predicting network traffic conditions using future trip production and trip attraction and scaled baseline (calibrated) O-D trip table to match future total demand as constraints.

The organization of this paper is as follows. Section 2 provides an overview of the simplified PFE planning tool. Section 3 demonstrates how the simplified PFE planning tool can be implemented in practice using a small MPO in Utah as a case study. Section 4 provides some concluding remarks.

2. Simplified PFE Planning Tool

Path Flow Estimator (PFE), originally developed by Bell and Shields (1995) and further enhanced by Chen *et al*. (2005, 2009, 2010) and Chootinan *et al*. (2005), is a one-stage network observer capable of estimating path flows and path travel times using only traffic counts from a subset of network links. The basic idea is to find a set of path flows that can reproduce the observed link counts. The resulting path flows can be used to derive flows on other spatial levels, such as turning movement flows, unobserved link flows, O-D flows, production flows, attraction flows, and total demand. The flexibility of aggregating path flows at different spatial levels allows us to develop a simplified PFE planning tool that makes use of various existing (e.g., traffic counts) and planning data (e.g., socioeconomic and land use data) for estimating and forecasting network traffic in small MPOs. Figure 1 depicts an overall framework of using PFE as a simplified planning tool for estimating the base year O-D trip table and predicting future year network traffic conditions. The simplified PFE planning tool starts with the estimation of the base year O-D trip table using traffic counts and land use data. PFE requires traffic count data to estimate the base year O-D trip table while the land use data is an optional input in this process. Once the base year O-D trip table representing the current traffic condition is estimated, the tool reuses this trip table to predict future network traffic condition. The unique features of PFE make it a promising planning tool for modeling network traffic for small MPOs with limited resources. When only travel counts are available for model calibration, modeling network traffic with PFE can be more efficient than with a traditional four-step model, because PFE can produce estimates within an acceptable error bound in one estimation step.

2.1 Data Requirements

Unlike the conventional four-step model which requires extensive surveys for each step (i.e., socioeconomic and land use survey, household survey, roadside survey, internal and external survey, on-board transit survey, traffic counts, etc.), PFE just requires some existing field data and planning data that can be obtained in public domains.

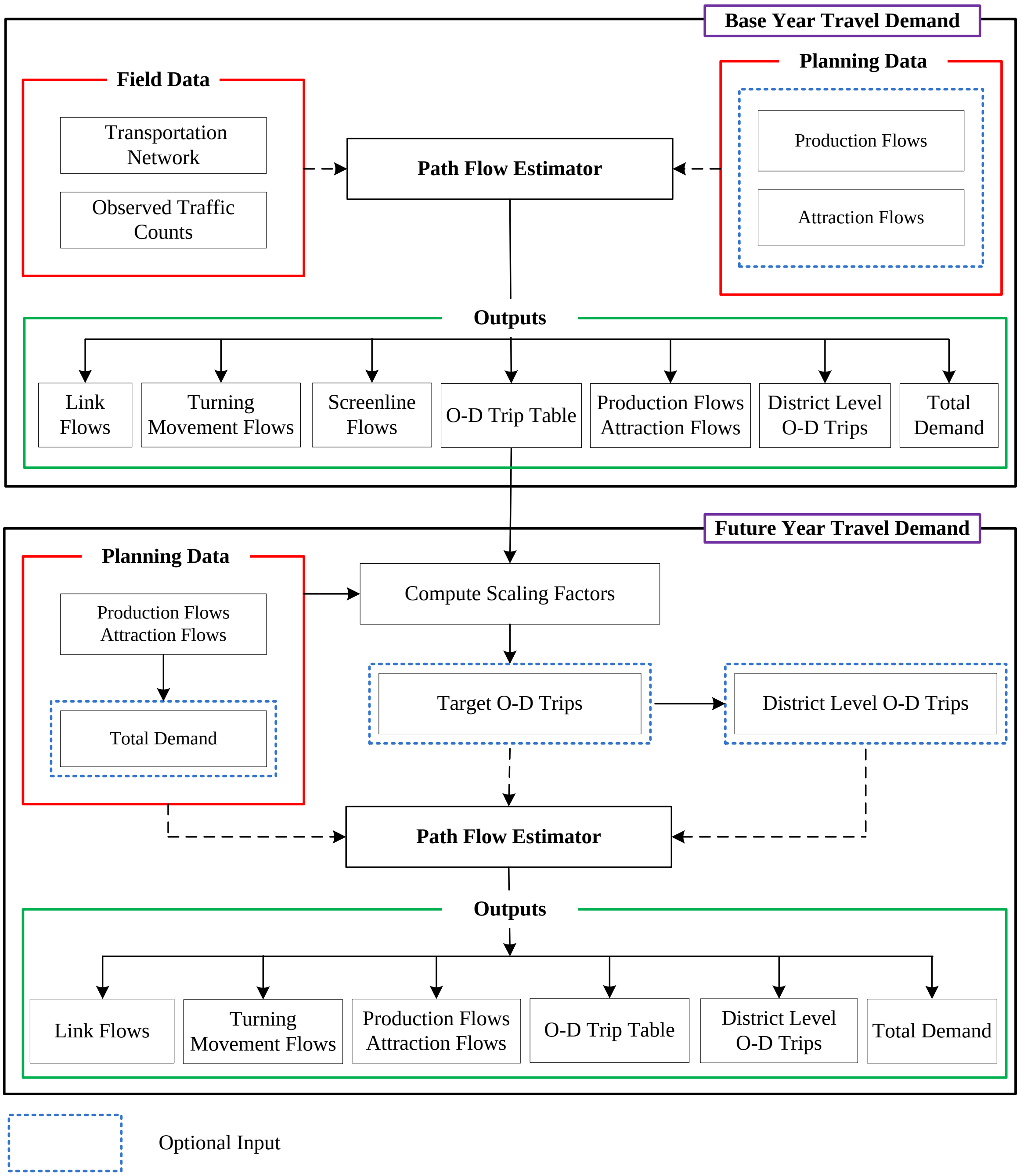


Figure 1 A simplified PFE planning tool framework

Base year field data and planning data include:

- *Observed traffic counts*: Traffic counts on streets and intersections are regularly conducted by various agencies (e.g., state department of transportation, the county, the city, the MPO, etc.). These observed traffic counts are collected in different formats: hourly traffic volume, annual average daily traffic (AADT), annual average weekday traffic (AAWT). Using the peak hour traffic (K-factor) and directional distribution (D-factors), it is possible to convert them into a common and usable format for PFE.

- *Zonal production and attraction flows*: In the absence of trip generation models, existing socio-economic and land use information available in public domain (e.g., population, employment, number of dwelling units, dwelling types, etc.) can be used to estimate zonal productions and zonal attractions. This requires using the Institute of Transportation Engineers (ITE) trip generation rates (ITE, 2008) to convert socio-economic and land use information to zonal productions and zonal attractions. Using the trip rates to reflect the trip-making propensity of the land use configuration in the study area is a common practice, and provides an economical and reasonable estimate when planning resources are limited.

- *Prior O-D trip table*: It is well known that O-D estimation from traffic counts is a highly underspecified problem (i.e., the number of O-D demands to be estimated is much greater than the number of independent traffic counts). Therefore, there are multiple O-D trip table estimates that can produce exactly the same link flows. In order to increase the observability of the O-D estimation problem from traffic counts, target (or outdated) O-D demands are commonly included to preserve the spatial distribution of the O-D demand pattern
- *Screenline flows*: A screenline is an imaginary line on a map that crosses one or more (typically several) links. It is often used as a validation criterion of regional flows by comparing the sum of observed traffic flows on links that are crossed by a screenline with the traffic assignment results for the same links and directions. Unlike the traditional four-step travel demand forecasting model that uses screenline flows as a post validation analysis of the traffic assignment results, screenline flows can be directly incorporated into PFE to estimate an O-D trip table that reproduces the regional flow patterns within

acceptable error bounds (e.g., 5 or 10 percent of actual volumes on the major routes in a freeway corridor or total corridor traffic).

- *Total demand*: Total demand is a useful measure to assess the overall traffic demand level in the study area.

Note that not all the data are required for the base year PFE. However, care should be used when selecting appropriate data to estimate the base year O-D trip table. Due to the non-availability of observed link flows in the future, the forecasting process for the future network traffic conditions needs to make full use of the planning data (i.e., future socio-economic and land use data) and the O-D demand pattern estimated in the base year. Future year planning data include:

- *Future zonal production and attraction flows*: Similar to the base year, future socio-economic and land use data can be used to generate future zonal production and attraction flow using the ITE trip generation rates.
- *Future target O-D trip table*: Since future traffic counts are not available, it is necessary to make use of the base year spatial demand distribution to preserve the trip-making pattern in the future year.
- *Target district-level O-D trip table*: In order to increase the observability of the future year PFE, district-level O-D demands can also be included to better reflect the differential land use developments among the different zones.
- *Future total demand*: Similar to the base year, future total demand can be included to constrain the estimated total demand.

Note that only planning data and the base year O-D trip table are available for the future year (i.e., there are no field data in the future year). Similar to the base year, not all the data are required for the future year PFE. However, care should be used when selecting appropriate data to forecast the future network traffic conditions.

2.2 Base Year PFE Mathematical Programming Formulation

The core component of PFE is a logit-based path choice model in which the perception errors of path travel times are assumed to be independently and identically Gumbel variate. The logit model interacts with link cost functions to produce a stochastic user equilibrium (SUE) traffic pattern. The aim of the base year PFE is to adapt the PFE to take not only field data (e.g., traffic counts, turning movement counts, and screenline flows) but also planning data (e.g., zonal production and attraction flows, target O-D trip table, and total demand) to estimate the base year O-D trip table. Hereafter, the following notation in Table 1 is considered.

Table 1 Notation

Notation	Description
Set of Variables	
M	: Set of network links with measurements
U	: Set of network links without measurements
A	: Set of all network links $A = M \cup U$
R	: Set of origins
S	: Set of destinations
I	: Set of intersections
RS	: Set of O-D pairs
H	: Set of district-level O-D pairs
L	: Set of screenlines
K_{rs}	: Set of paths connecting origin *r* and destination *s*
$\bar{I}$	: Set of intersections with measurements
$\bar{R}$	: Set of origins with planning data
$\bar{S}$	: Set of destinations with planning data
$\bar{R}\bar{S}$	: Set of target (or prior) O-D pairs
M_i	: Set of turning movements at intersection *i*
In_i	: Set of links terminating into of intersection *i*
Out_i	: Set of links originating out of intersection *i*
Input Variables and Parameters	
v_a	: Observed traffic volume on link *a*

Table 1 (Cont.) Notation

Notation	Description
C_a	: Capacity of link *a*
g_m^i	: Observed traffic volume on turning movement *m* of intersection *i*
O_r	: Observed trip production of origin *r* obtained by converting land use data via the ITE trip rates
D_s	: Observed trip attraction of destination *s* obtained by converting land use data via the ITE trip rates
z_{rs}	: Target O-D flows between origin *r* and destination *s*
c_l	: Observed flow on screenline *l*
F	: Target total demand
b_h	: Target flows of district-level O-D pair *h*
ε_a	: Percentage measurement error allowed for the traffic count on link *a*
ε_m^i	: Percentage measurement error allowed for turning movement *m* of intersection *i*
ε_r	: Percentage measurement error allowed for trip production of origin *r*
ε_s	: Percentage measurement error allowed for trip attraction of destination *s*
ε_{rs}	: Percentage measurement error allowed for the target O-D demands between origin *r* and destination *s*
ε_l	: Percentage measurement error allowed for screenline *l*
ε	: Percentage measurement error allowed for the target total demand
ε_h	: Percentage measurement error allowed for district-level O-D pair *h*
θ	: Dispersion parameter in the logit model
$t_a(\cdot)$	: Travel time on link *a*
δ_{ka}^{rs}	: Path-link indicator, 1 if link a is on path *k* between O-D pair *rs* and 0 otherwise

Table 1 (Cont.) Notation

Notation	Description
Output and Decision variables	
f_k^{rs}	: Flow on path *k* connecting O-D pair *rs*
x_a	: Estimated traffic volume on link *a*
t_m^i	: Estimated flow on turning movement *m* at intersection *i*
P_r	: Estimated trip production of origin *r*
A_s	: Estimated trip attraction of destination s
q_{rs}	: Estimated O-D flows between origin *r* and destination *s*
s_l	: Estimated flow on screenline *l*
T	: Estimated total demand
w_h	: Estimated flows of district-level O-D pair *h*

Based on the equivalent mathematical programming formulation given by Fisk (1980), the base year PFE formulation can be formulated as a convex program with various side constraints as follows.

Minimize: $$\frac{1}{\theta}\sum_{rs\in \mathrm{RS}}\sum_{k\in \mathrm{K}_{rs}} f_k^{rs}(\ln f_k^{rs}-1)+\sum_{a\in \mathrm{A}}\int_0^{x_a} t_a(\omega)d\omega \quad (1)$$

subject to: $$(1-\varepsilon_a)\cdot v_a \le x_a \le (1+\varepsilon_a)\cdot v_a, \quad \forall a\in \mathrm{M}, \quad (2)$$

$$x_a \le C_a, \forall a\in \mathrm{U}, \quad (3)$$

$$(1-\varepsilon_m^i)\cdot g_m^i \le t_m^i \le (1+\varepsilon_m^i)\cdot g_m^i, \quad \forall m\in \mathrm{M}_i, i\in \bar{\mathrm{I}}, \quad (4)$$

$$(1-\varepsilon_r)\cdot O_r \le P_r \le (1+\varepsilon_r)\cdot O_r, \quad \forall r\in \bar{\mathrm{R}}, \quad (5)$$

$$(1-\varepsilon_s)\cdot D_s \le A_s \le (1+\varepsilon_s)\cdot D_s, \quad \forall s\in \bar{\mathrm{S}}, \quad (6)$$

$$(1-\varepsilon_{rs})\cdot z_{rs} \le q_{rs} \le (1+\varepsilon_{rs})\cdot z_{rs}, \quad \forall rs\in \bar{\mathrm{R}}\bar{\mathrm{S}}, \quad (7)$$

$$(1-\varepsilon_l)\cdot c_l \le s_l \le (1+\varepsilon_l)\cdot c_l, \quad \forall l\in \mathrm{L}, \quad (8)$$

$$(1-\varepsilon)\cdot F \le T \le (1+\varepsilon)\cdot F\ , \tag{9}$$

$$f_k^{rs} \ge 0,\ \forall k \in \mathrm{K_{rs}}, rs \in \mathrm{RS}, \tag{10}$$

where

$$x_a = \sum_{rs\in \mathrm{RS}} \sum_{k\in \mathrm{K_{rs}}} f_k^{rs}\delta_{ka}^{rs}, \qquad \forall\ a \in \mathrm{A}\ , \tag{11}$$

$$t_m^i = \sum_{rs\in \mathrm{RS}} \sum_{k\in \mathrm{K_{rs}}} \sum_{a\in \mathrm{IN}_i} \sum_{b\in \mathrm{OUT_i}} f_k^{rs}\delta_{ka}^{rs}\delta_{kb}^{rs}, \qquad \forall\ m \in \mathrm{M}_i, i \in \mathrm{I} \tag{12}$$

$$P_r = \sum_{s\in \mathrm{S}} \sum_{k\in \mathrm{K_{rs}}} f_k^{rs},\ \forall r \in \mathrm{R}, \tag{13}$$

$$A_s = \sum_{r\in \mathrm{R}} \sum_{k\in \mathrm{K_{rs}}} f_k^{rs},\ \forall s \in \mathrm{S}, \tag{14}$$

$$q_{rs} = \sum_{k\in \mathrm{K_{rs}}} f_k^{rs}, \qquad \forall\ rs \in \mathrm{RS}\ , \tag{15}$$

$$s_l = \sum_{a\in l} \sum_{rs\in \mathrm{RS}} \sum_{k\in \mathrm{K_{rs}}} f_k^{rs}\delta_{ka}^{rs},\ \ \forall l \in \mathrm{L}\ , \tag{16}$$

$$T = \sum_{rs\in \mathrm{RS}} \sum_{k\in K_{rs}} f_k^{rs} \tag{17}$$

The objective function (1) has two terms: an entropy term and a user equilibrium term. The entropy term seeks to spread trips onto multiple paths according to the dispersion parameter, while the user equilibrium term tends to cluster trips on the minimum cost paths. As opposed to the traditional logit-based SUE model, PFE finds path flows that minimize the SUE objective function while simultaneously reproducing traffic counts on all observed links in Equation (2), turning movement counts on all observed intersections in Equation (4), zonal production and attraction of certain origin and destination in Equations (5) and (6), prior travel demands of certain O-D pairs in Equation (7), screenline flows in Equation (8), and total demand in Equation (9) within some predefined error bounds. These error bounds are essentially confidence levels of the observed data at different spatial levels used to constrain the path flow estimation. A more reliable data will use a smaller error bound (or tolerance) to constrain the estimated flow within a narrower range, while a less reliable data will use a larger tolerance to allow for a larger range of the estimated flow. For the unobserved links, the estimated flows cannot exceed their respective capacities as indicated by Equation (3). This constraint is incorporated for the same purpose as in the capacitated traffic assignment Larsson and Patriksson (1995), which is to prevent producing unrealistically high link flow estimates. Equation (10) constrains the path flows to be non-negativity. Equations (11), (12), (13), (14), (15), (16) and (17) are definitional constraints that sum up the estimated path flows to obtain the link flows, intersection turning movement flows, zonal production flows, zonal attraction flows, O-D trips, screenline flows, and total demand, respectively.

2.3 Future Year PFE Mathematical Programming Formulation

The future year PFE formulation can be formulated as a convex program with various side constraints as follows.

Minimize: $$\frac{1}{\theta}\sum_{rs\in \mathrm{RS}}\sum_{k\in \mathrm{K}_{rs}} f_k^{rs}(\ln f_k^{rs}-1)+\sum_{a\in \mathrm{A}}\int_0^{x_a} t_a(\omega)d\omega \quad (18)$$

subject to: $$(1-\varepsilon_r)\cdot O_r \le P_r \le (1+\varepsilon_r)\cdot O_r, \quad \forall r\in \bar{\mathrm{R}}, \quad (19)$$

$$(1-\varepsilon_s)\cdot D_s \le A_s \le (1+\varepsilon_s)\cdot D_s, \quad \forall s\in \bar{\mathrm{S}}, \quad (20)$$

$$(1-\varepsilon_{rs})\cdot z_{rs} \le q_{rs} \le (1+\varepsilon_{rs})\cdot z_{rs}, \quad \forall\, rs\in \bar{\mathrm{R}}\bar{\mathrm{S}}, \quad (21)$$

$$(1-\varepsilon_h)\cdot b_h \le w_h \le (1+\varepsilon_h)\cdot b_h, \quad \forall\, h\in \mathrm{H}, \quad (22)$$

$$(1-\varepsilon)\cdot F \le T \le (1+\varepsilon)\cdot F, \quad (23)$$

$$f_k^{rs}\ge 0, \quad \forall k\in \mathrm{K}_{rs}, rs\in \mathrm{RS}, \quad (24)$$

where

$$x_a=\sum_{rs\in \mathrm{RS}}\sum_{k\in \mathrm{K}_{rs}} f_k^{rs}\delta_{ka}^{rs}, \quad \forall\, a\in \mathrm{A}, \quad (25)$$

$$t_m^i=\sum_{rs\in \mathrm{RS}}\sum_{k\in \mathrm{K}_{rs}}\sum_{a\in \mathrm{IN}_i}\sum_{b\in \mathrm{OUT}_i} f_k^{rs}\delta_{ka}^{rs}\delta_{kb}^{rs}, \quad \forall\, m\in \mathrm{M}_i, i\in \mathrm{I} \quad (26)$$

$$P_r=\sum_{s\in \mathrm{S}}\sum_{k\in \mathrm{K}_{rs}} f_k^{rs}, \ \forall r\in \mathrm{R}, \quad (27)$$

$$A_s=\sum_{r\in \mathrm{R}}\sum_{k\in \mathrm{K}_{rs}} f_k^{rs}, \ \forall s\in \mathrm{S}, \quad (28)$$

$$q_{rs}=\sum_{k\in \mathrm{K}_{rs}} f_k^{rs}, \quad \forall\, rs\in \mathrm{RS}, \quad (29)$$

$$w_h = \sum_{rs \in h} \sum_{k \in K_{rs}} f_k^{rs}, \forall h \in \mathrm{H}, \tag{30}$$

$$T = \sum_{rs \in \mathrm{RS}} \sum_{k \in K_{rs}} f_k^{rs} \tag{31}$$

Similar to the base year PFE, the objective function in Equation (18), zonal production and zonal attraction constraints in Equations (19) and (20), target O-D flow constraints in Equation (21), total demand constraint in Equation (23), and path flow non-negativity constraints in Equation (24) are the same as those in the base year, except that these equations are applied in the future year. To increase the observability of the future year PFE, district-level O-D flow constraints in Equation (22) are included to better reflect the differential land use developments among the different zones. Equations (25)-(31) are the definitional constraints that define the link flows, intersection turning movement flows, zonal production and attraction flows, target O-D flows, target district-level O-D flows, and total demand, respectively.

2.4 Solution Procedure

The solution procedure for solving the simplified PFE planning tool (both base year and future year) consists of three main modules: (1) iterative balancing scheme, (2) column (or path) generation, and (3) output derivation from path flows. The basic idea of the iterative balancing scheme is to sequentially scale the path flows to fulfill one constraint at a time by adjusting the dual variables. Once the scheme converges, the path flows can be analytically determined. A column generation is included in the solution procedure to avoid path enumeration for a general transportation network. Finally, an output derivation procedure is used to derive information at different spatial levels using the path-flow solution from PFE (e.g., link flows, turning movement flows for all intersections, production flows, attraction flows, O-D flows, screen-line flows, and total demand). For details of the solution procedure, please refer to Bell and Shields (1995), Chen *et al*. (2005, 2009, 2010), and Chootinan *et al*. (2005).

3. Case Study

In this section, a case study is conducted using the Cache Metropolitan Planning Organization (CMPO) network in Utah. According to the 2008 U.S. Census U.S. Census (2010), CMPO is classified as a small-sized MPO (i.e., total population is 110,025). The majority area of CMPO is a broad agricultural valley located in northern Utah. Although most of the areas are rural areas, yet recent growth has added an urban flavor in many cities within the Cache County (e.g., Logan). Logan City is an urbanized area within the Cache County, and has the largest portion of population and employment. The land use in Cache County is a mixture of residential, commercial, and industrial areas. Higher densities of both residential and commercial activities are concentrated in Logan and they are decreasing from the center to the edges of urbanized area. Figure 2 shows the CMPO network classified by roadway functional class and the designated traffic analysis zones (TAZs). The regional main road US-91 runs north and south serving as Logan's Main Street and connecting to I-15 in Box Elder County. The US 89/91 corridor carries bulk of the traffic in the Cache County. There are 310 internal TAZs and 7 external TAZs in CMPO network.

3.1 Base Year Model Development

The base year model data was developed based on observed link counts data and socioeconomic and land use data in year 2008. The socioeconomic and land use data were obtained from the Governor's Office of Planning and Budget Governor's Office of Planning and Budget (2009). The model uses household population and number of households as the controls for trip productions and employments for trip attractions. The employments are categorized to retails, industrials and others (e.g., office). The observed traffic counts data were obtained from the Utah Department of Transportation (2009). The AADT data includes 285 locations (i.e., 139 collectors, 96 minor arterials, and 50 principle arterials). Note that data preprocessing (e.g., traffic counts, land use data obtained from different secondary data sources, etc.) was required to remove errors and inconsistencies in order to avoid getting erroneous results. The error bounds of traffic counts were specified using the Federal Highway Administration (FHWA) guidelines: Freeway (+/- 7%), major arterial (+/- 10%), minor arterial (+/- 15%), and collector (+/- 25%).

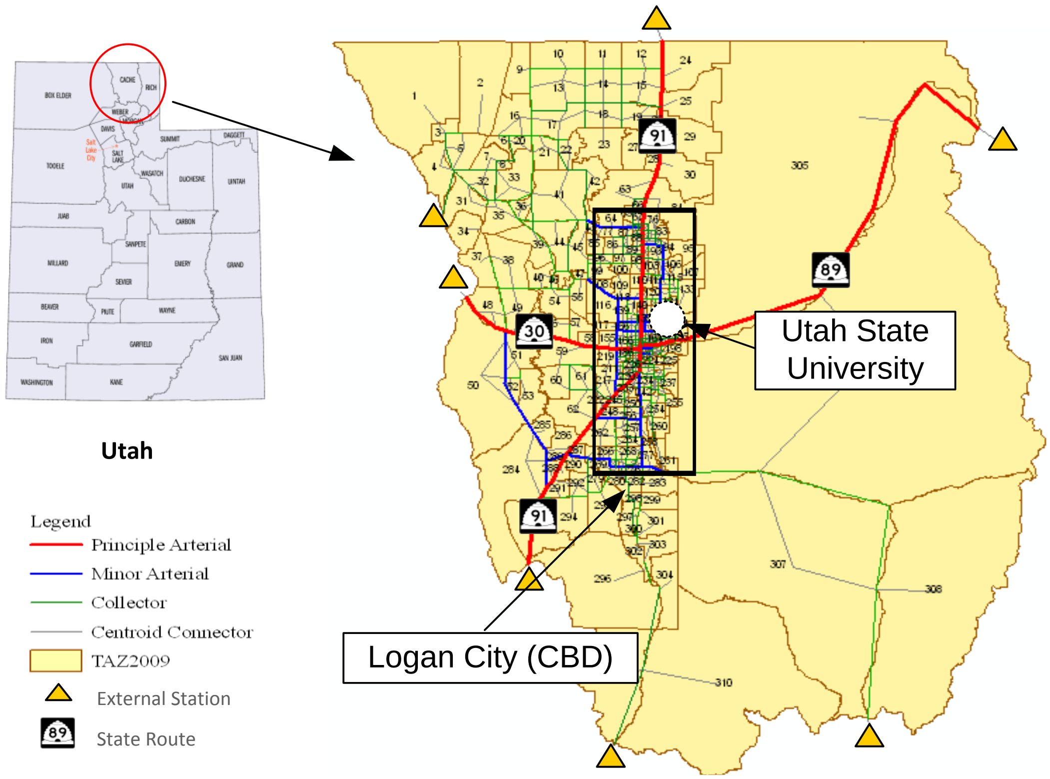


Figure 2 CMPO network with roadways classified by functional class and TAZs

Two scenarios are set up for the base year PFE model:

- Scenario 1: Link counts only (Base Case)
- Scenario 2: Link counts + land use data

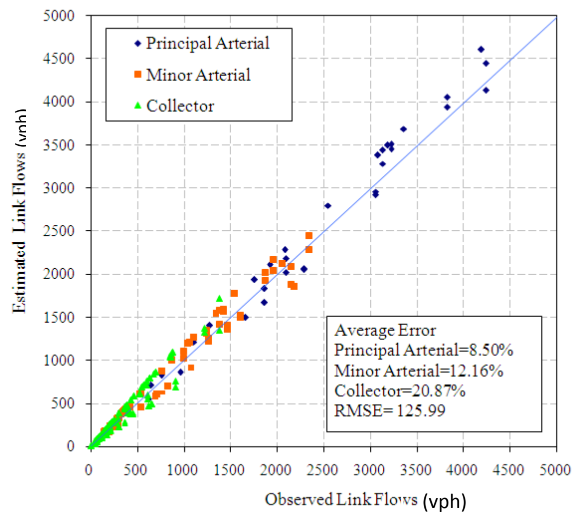
Scenario 1 uses link counts only for the base year estimation, while scenario 2 increases the observability by adding selected zonal production and attraction flows to scenario 1 to estimate the base year O-D trip table. Accuracy of the estimates can be measured by the root mean square error (RMSE) as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(x_{est}^{n} - x_{obs}^{n})^2} \quad (32)$$

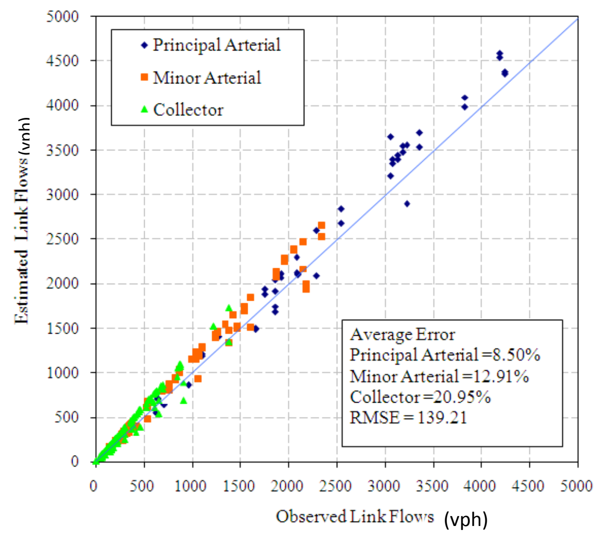
where N is the number of observations, x_{est} and x_{obs} are the estimated and observed values, respectively.

3.2 Base Year Results

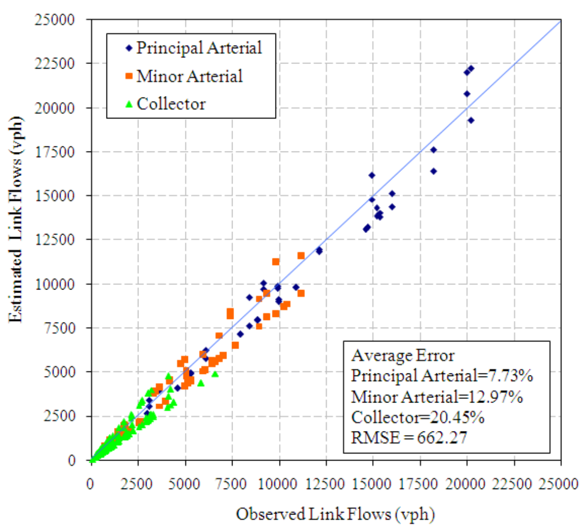
Figure 3 shows the scatter plots of observed and estimated link flows by roadway functional class in two periods (AM peak from 6 to 9 AM and daily traffic) for both scenarios. The errors classified by roadway functional class are also reported in the figure. The results show that the base year PFE can estimate link flows within the acceptable ranges (i.e., +/- 10% for principle arterial, +/- 15% for minor arterial, and +/- 25% for collector for the time periods and both scenarios.



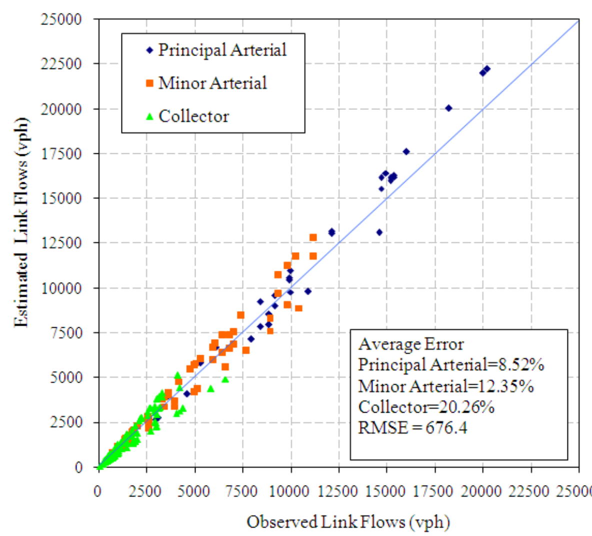
(a) Scenario 1 (AM peak)



(b) Scenario 2 (AM peak)



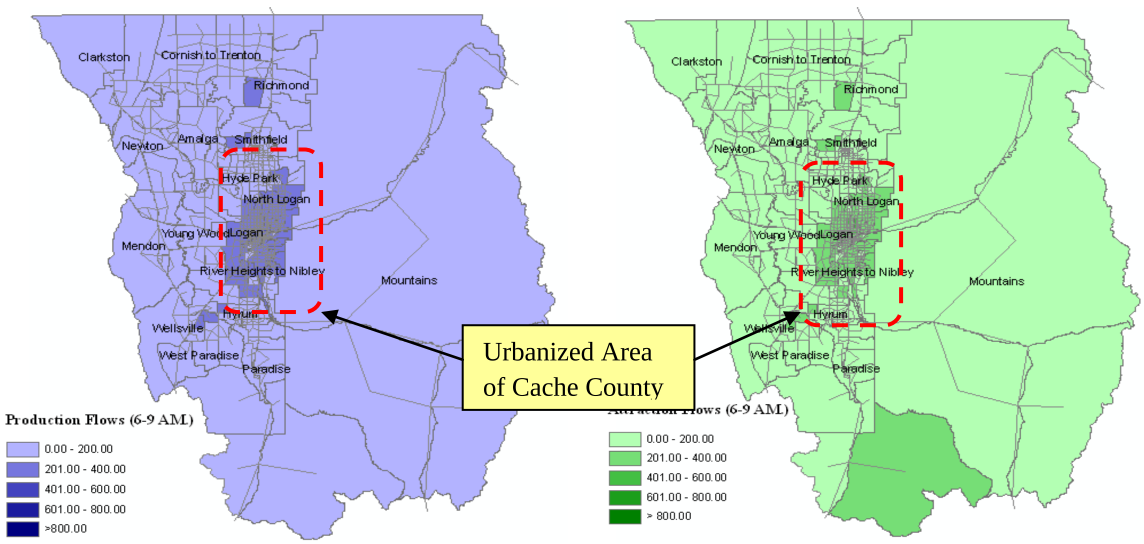
(c) Scenario 1 (daily traffic)



(d) Scenario 2 (daily traffic)

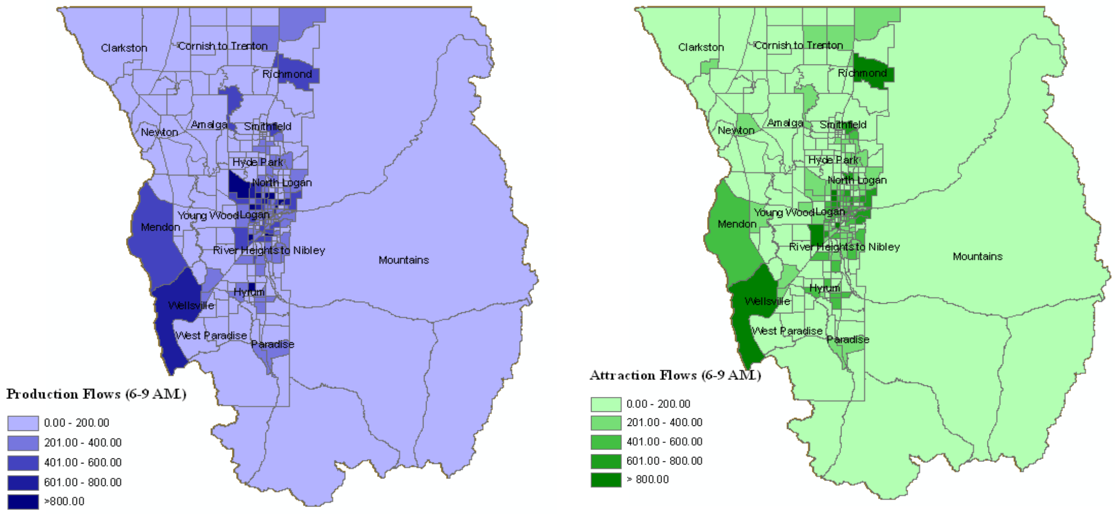
Figure 3 Comparisons of observed and estimated link flows for AM peak and daily traffic

Between the two scenarios, including land use data into the estimation slightly deteriorates the matching of link counts as indicated by the higher RMSEs. However, this is compensated by better estimates of zonal production and attraction flow as shown in Figure 4. Figures 4a and 4b show the production and attraction trips for scenario 1 (base case) and Figures 4c and 4d for scenario 2. As can be seen, trip productions and attractions for the base case are relatively concentrated along Highway 91 (Main Street in the City of Logan) and residential development radiating out from the urbanized area of Cache County (see Figures 4a, 4b). However, the trip productions and attractions are more spatially distributed when the land use data are considered in the estimation process. Between the two scenarios estimated by the base year PFE, scenario 1 underestimates some of the zonal production and attraction flows in the west side of the county (i.e., Wellsville and Mendon) compared to those in scenario 2. The reason is that the estimation in scenario 1 is constrained by only traffic counts. By adding selected zonal production and attraction flows as constraints in scenario 2, it can improve the observability of the trip generation pattern.



(a) Trip production (Scenario 1)　　(b) Trip attraction (Scenario 1)

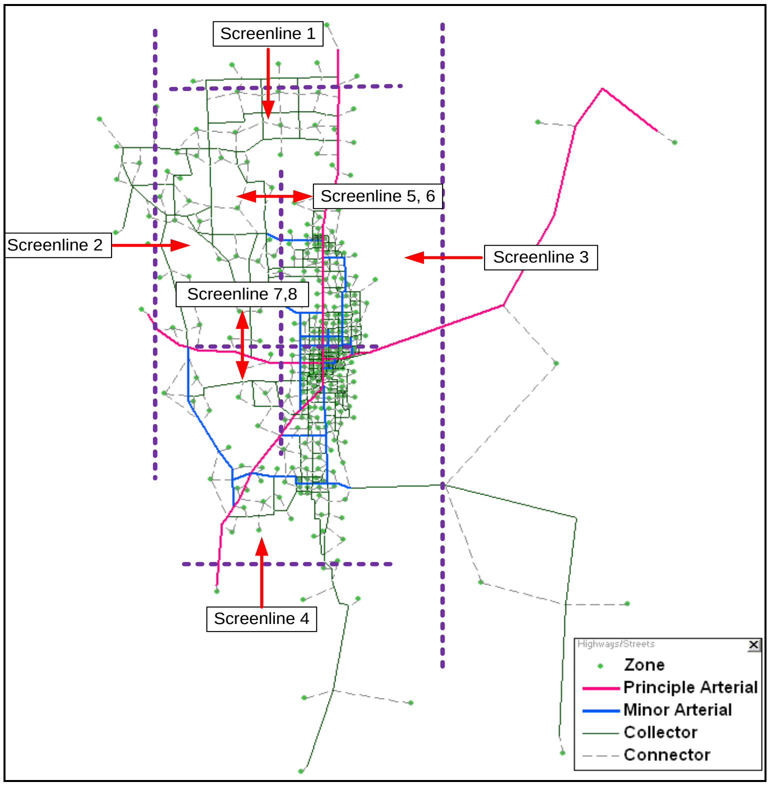
Figure 4 Estimated production and attraction flows for AM peak



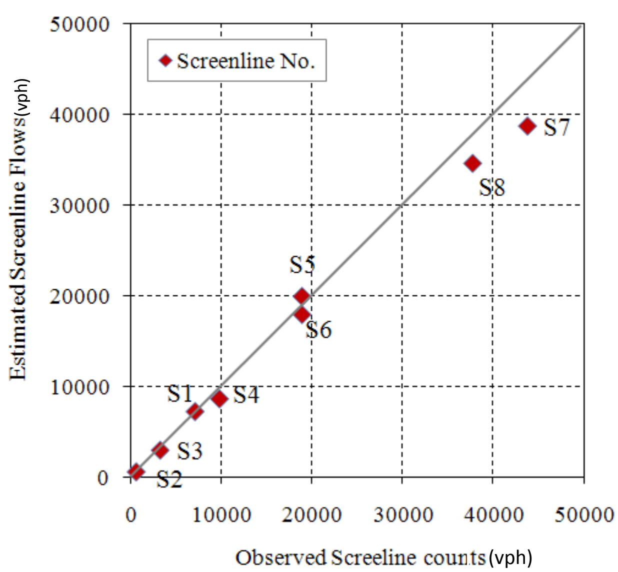
(c) Trip production (Scenario 2)　　　(d) Trip attraction (Scenario 2)

Figure 4 (Cont.) Estimated production and attraction flows for AM peak

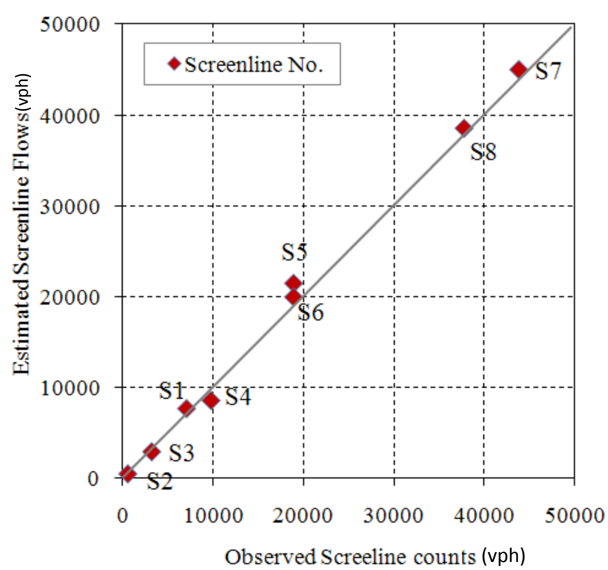
Moreover, we provide the comparison of estimated and observed screenline flows in Figure 5. Figure 5a shows the locations of eight screenlines in the study area. As can be seen, screenlines 1 to 4 are located to cordon off the study area, while screenlines 5 to 8 are located to capture the traffic moving in and out the CBD area (i.e., City of Logan). The arrowhead in each screenline refers to the direction of traffic (e.g., leftward arrow: eastbound direction). Figures 5b and 5c shows the scatter plots of the observed and estimated screenline flows for both scenarios using the daily traffic. Majority of the screenline flows can be estimated within the acceptable range as specified by FHWA (i.e., within ±10 percent of the observed values). These figures also reveal that the screenline flows are slightly underestimated when using only link counts, but are better matched when incorporating the land use data. Note that the low screenline flows are the ones that cut through the rural areas and national forest (i.e., screenline 2 for the rural areas and screenline 3 for the national forest).



(a) Locations of screenlines in Cache County



(b) Scenario 1



(c) Scenario 2

Figure 5 a) Locations of screenlines in Cache County

b), c) Comparison of observed and estimated screenline flows for daily traffic

3.3 Future Year Model Development

This section demonstrates how to apply the future year PFE with future land use data and the base year trip table to predict future network traffic conditions. Future zonal productions and attractions can be estimated from the land use plan of the study area via ITE trip generation rates. The O-D trip table estimated from the base year is used to constrain the relationship of travel impedance and trip interchange between each O-D pair in the forecasting process. For simplicity, we compute the scaling factor from the ratio of future year total demand to base year total demand. In addition, the district-level O-D demands are included to increase the observability of the future year PFE to better reflect the differential land use developments among the different zones. In our case study, the 310 internal TAZs are grouped to 24 districts based on the cities in Cache County. District-level O-D flows with greater than 300 trips during AM peak and 1,000 trips for daily traffic are then used as constraints in the future year PFE for forecasting. According to the CMPO 2030 Regional Transportation Plan (CMPO, 2007), two scenarios are set up as follows.

- Scenario 1: No build scenario
- Scenario 2: Build scenario

For the "build" scenario, four projects from the "Priority 1" list (CMPO, 2007) are used to revise the CMPO network. These transportation improvement projects mainly expand the existing roadways by widening to 80 feet right of way (ROW) and widening to four lanes (see Figure 6 for the project locations). PFE forecasting is then performed to predict future network traffic condition for the two scenarios considered above.

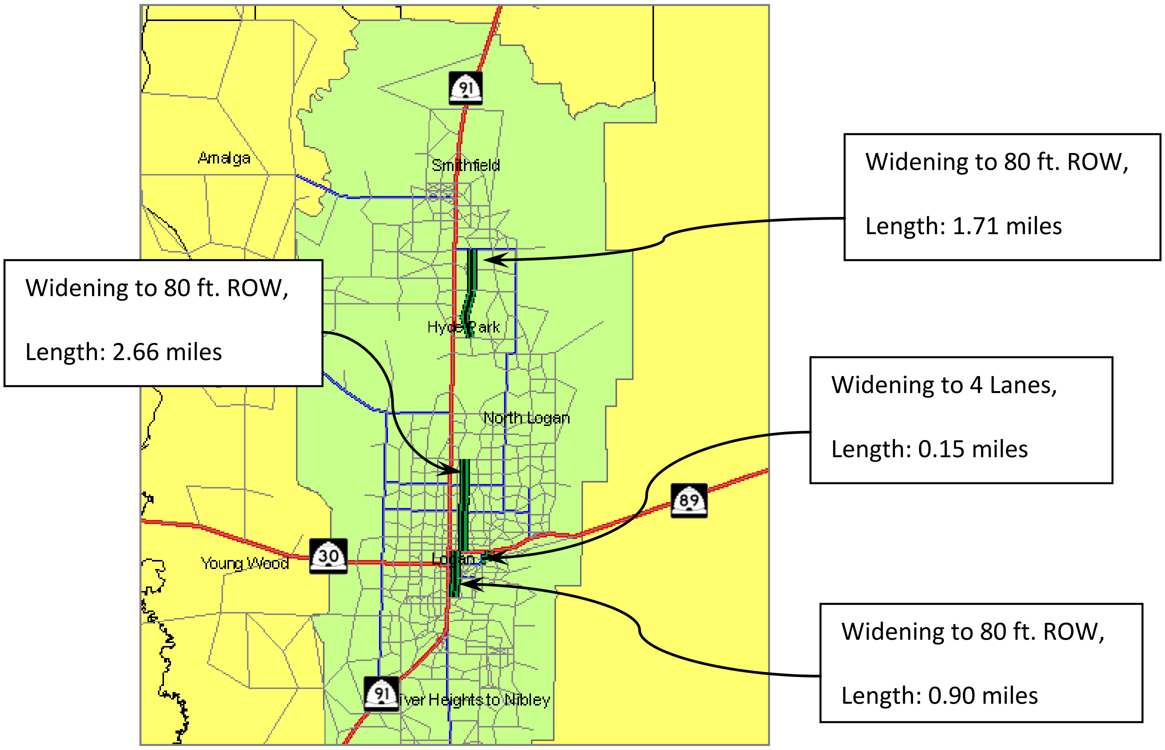


Figure 6 Project locations for the build scenario

3.4 Forecasting Future Network Traffic Condition

Since there are no observed future traffic conditions, the forecast results can only be assessed based on its reasonableness. Figure 7 shows the forecast results in terms of volume to capacity (V/C) ratios for both scenarios during the AM peak. As expected, congestion level is slightly higher in scenario 1 (no build scenario) compared to those in scenario 2 (build scenario). It appears that by expanding the four transportation improvement projects can help to alleviate some of the congestion on Main Street along the downtown of Logan City and U.S. 91 heading toward Smithfield. Selected links in the CMPO network are highlighted in Figure 7 to show the improved V/C ratios for the "no build" and "build" scenarios. To further assess the reasonableness of the forecast results, vehicle hours traveled (VHT) is used as an aggregate measure for the whole CMPO network to compare the "no build" and "build" scenarios. Figure 8 depicts the VHT of both AM peak and daily traffic for both scenarios. As can be seen, the results show some minor improvement in VHT on the principle arterials and collectors, and a negligible deterioration in VHT on the minor arterials. These results are somewhat expected because some traffic divert from Main Street (a principle arterial) to some minor arterials after the roadway expansions. Nevertheless, we can observe the VHT for the whole CMPO network improves about 3% for AM peak and 2% for daily traffic. These total travel time savings converted to monetary value using the MicroBENCOST guidelines (TTI, 1993) are about \$31,295 per day or \$8.1 million per year (assuming the value of time for Cache County in Utah in 2008 equals to \$11.24/hour and 260 workdays/year). The construction cost for these four improvement projects is about \$14.2 million. This means over a five-year period with a modest annual percentage rate, the project cost should be recovered. In other words, the transportation improvement projects in this case study are worthwhile.

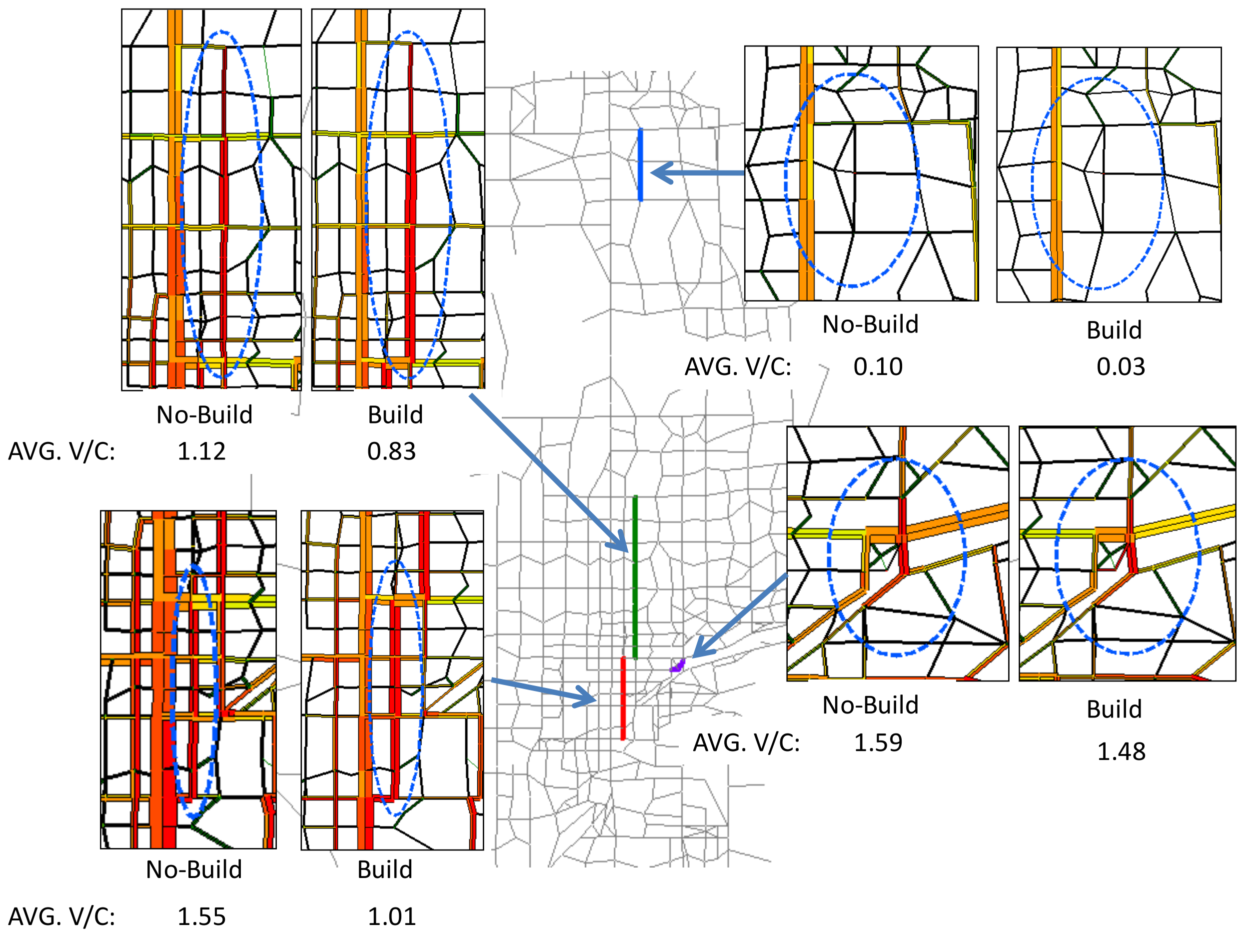
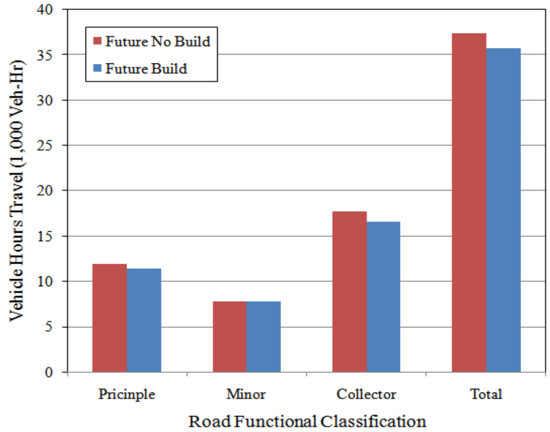
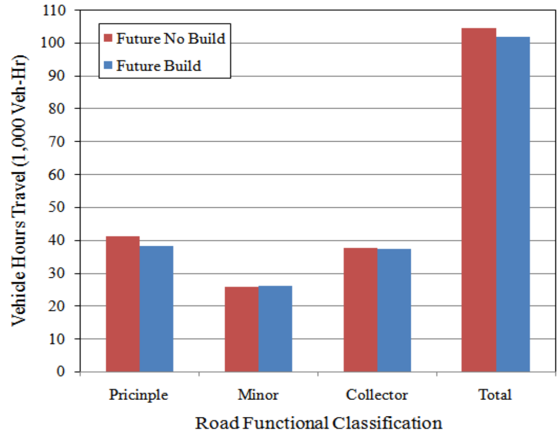


Figure 7 Level of service map for both scenarios during the AM peak



(a) AM peak



(b) Daily traffic

Figure 8 Vehicle-hour traveled by roadway functional class for AM peak and daily traffic

4. Conclusions and Future Research

A simplified planning tool specifically targeted at small MPOs was developed in this paper to model network traffic for planning applications. This planning tool used PFE for both base year estimation and future year forecasting with some existing field data and planning data that can be obtained in public domains. A case study was conducted using a small MPO in Utah to demonstrate how the tool can be implemented in practice. Two scenarios (traffic counts only and traffic counts plus land us data) were set up to test the impact of using different input data for the base year estimation. The results of link flow estimates matched observed data within satisfactory error bounds. The results also showed satisfactory spatial distribution of trip makings when the estimation was constrained on both traffic counts and trip production and attraction flows (converted from land use volumes using ITE trip generation rates). For validation purpose, estimated and observed screenline flows were compared. The results showed majority of the screenline flows were estimated within the acceptable range as specified by FHWA. Forecasting of future traffic was also accomplished with PFE by constraining the estimation on a scaled baseline (or target) O-D trip table, future trip production and attraction flows and selected district-level O-D demands. The impacts of transportation improvement projects were evaluated and shown to be worthwhile for the case study.

In addition, future research is needed to model PFE to incorporate the different types of constraints: screenline flows, trip length frequency distribution and address for different modes (e.g., bus, truck). Based on the experience gained from the case study, the proposed planning tool is applicable for small MPOs with limited resources. In the absence of travel survey data, the proposed method uses similar data (land use volumes and traffic counts) as a four-step model for model development and calibration. Since ITE trip generation rates are used in the modeling process, the analysis scope and results are consistent with those of short-range, localized transportation improvement programs. Future research is needed to enhance the proposed approach such that the impacts of long-range, area-wide growth can be modeled within the same framework. Mode choice should be included in the tool to assess the impact of adding a transit system or expanding an existing one. In addition, more case studies should be conducted to further validate the usefulness of the simplified PFE planning tool.

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