Modeling Network Traffic for Planning Applications in a Small Community

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Abstract: A procedure is developed to model network traffic for planning applications in small and/or medium-sized communities with limited planning resources. The proposed method is based on the theories and assumptions of conventional four-step travel demand models, but the baseline trip table is estimated from existing traffic counts using path flow estimator (PFE) to render a quick response approach that requires less data than the conventional approach. The proposed modeling approach is suitable for short-range, small area planning applications, such as the evaluation of alternative roadway networks that does not involve significant growth in trip generation patterns. A case study is set up with data from a small community (St. Helena, Calif.) to demonstrate the proposed approach. An *O-D* trip table is estimated with PFE from traffic counts. The estimation process is shown to be feasible as the results matched observed data with a satisfactory error bound. The traffic impacts of various scenarios of land use and network changes can be effectively evaluated with the proposed modeling approach.

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Introduction

The City of St. Helena is located in the famous wine-producing region of Napa Valley in California, approximately 104.6 km (65 mil) north of San Francisco. St. Helena is a full service city with a population of 6,019 (as of January 1, 2002) within an area of 10.36 km^2 (4 mi^2). The primary planning goal of the city is to reserve the rural, small town quality and agricultural character. Nevertheless, in the past few years, the city has been faced with the pressures to grow due to the rising demand for service and commercial activities brought upon by the increased number of tourists to Napa Valley every year. The pressure for regional growth has caused serious concerns in the community with regards to deteriorating traffic conditions and small town atmosphere. To accommodate the needs for development, the city designated an area within the city boundary as a specific plan area to carefully guide and support future development of properties within the area while maintaining the desired town characteristics. The specific plan proposes to relieve congestion on Highway 29 by extending a street that runs parallel to the highway. The identification of potential traffic impacts and the decision making for right-of-way preservation are hinged upon a reliable forecast of design year traffic volumes on the extended street. However, the city's planning department has neither an existing travel model nor the budget for a full model development. The dilemma calls for innovative modeling approaches that can provide quick and reasonable responses with available resources. The objective of this case study is to demonstrate an alternative methodology to model network traffic for planning applications in a small and/or medium-sized community such as St. Helena. The proposed method is built upon the theories and assumptions of conventional travel models, but innovative use of existing analytical techniques enables forecasting of roadway traffic with a simplified procedure and less data (City of Helena 1993).

The proposed procedure starts with the estimation of a baseline trip table from traffic counts. The method is introduced by Turnquist and Gur (1979) for the evaluation of short-range, subregional traffic improvement plans. They noted that estimating trip tables from traffic counts represents a cost-effective alternative to conventional trip generation and distribution models that depend on expensive, time-consuming surveys and labor-intensive data preparation and analyses. Because many jurisdictions regularly conduct traffic counts on streets and intersections, estimating trip tables from observed traffic volumes can also significantly reduce the effort and time associated with data collection. However, Turnquist and Gur's study deals exclusively with the estimation of trip table. It does not demonstrate how the method can be used in the modeling process when changes in land use and transportation network are expected. In addition, Turnquist and Gur's method of using traffic counts to infer an *O-D* matrix faces technical issues such as equilibrium observed flow pattern and uniqueness (Yang et al. 1994).

We propose to estimate trip tables from existing traffic counts

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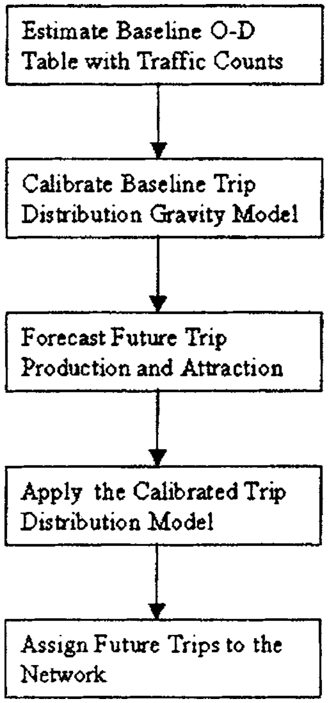

Fig. 1. Flow chart of modeling procedure

using the path flow estimator (PFE) that has superior theoretical foundation and tractability. PFE, originally developed by Bell and Shield (1995), can estimate path flows and path travel times using a subset of network traffic counts data. Because a unique set of path flows is readily available from the PFE, trip tables can be estimated by simply adding up the flows on all paths connecting each *O-D* pair. The theoretical advantage of PFE lies in the assumption of stochastic user equilibrium (SUE). SUE assumes that travelers would choose nonequal travel time paths due to imperfect knowledge of network travel times. Although the size of the street network in St. Helena is relatively small, it's determined that the SUE assumption is valid, since many of the city's trip makers are out-of-town tourists. In addition, PFE does not require all links to be observed to generate *O-D* estimation. Once the trip table representing the existing traffic condition is estimated, the proposed procedure uses this trip table as the basis to estimate future trip table that reflects proposed land use and network changes. The future trip table is then assigned to the network to forecast the amount of traffic on various alternative networks under consideration. The flow chart of proposed procedure is illustrated in Fig. 1. A case study using empirical data from the City of St. Helena is set up to demonstrate how the method can be implemented in practice.

Case Study

Historical traffic counts collected in St. Helena since 2001 are retrieved for estimation of the baseline trip table with PFE. Link volumes collected during the evening peak hour, the time of day when traffic congestion on Highway 29 presents a serious issue, are assembled and a network with 28 traffic analysis zones (TAZs) is coded with the observed link volumes. Through trips, estimated with field observation passing St. Helena through Highway 29, are inferred from the traffic counts. The network contains 113 links and 54 of the links do not have traffic count data. Turn

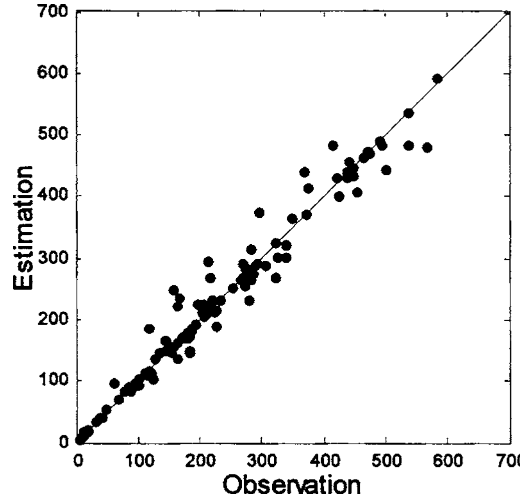

Fig. 2. PFE estimation discrepancy

penalties, based on the actual traffic conditions, are also coded with the network such that the shortest paths among TAZs replicate actual travel patterns in the area. PFE is applied for the estimation of an *O-D* trip table. The accuracy in terms of link flow estimates is presented in Fig. 2. As expected, PFE reproduces the observed traffic flows within an acceptable error bound. Accuracy of the estimates is measured by the root-mean-square error (RMSE) in Eq. (1)

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(x^n - v^n)^2} \quad (1)$$

where N=number of observations; and x and v=estimated and observed link volumes, respectively. The RMSE of PFE link flow estimates for the St. Helena network is 26.99.

The estimated baseline *O-D* table represents the region's travel demand pattern underlying the observed traffic counts. The sum of each row in the table represents a TAZ's vehicular trip production and the sum of each column represents the attraction. Theoretically, the estimated *O-D* trip table represents the most likely one among many potential solutions. Since the "true" *O-D* is difficult and expensive to obtain, the "correctness" of an estimated *O-D* trip table is often assessed by its similarity to one produced by the gravity model of the regional travel models. In this study, due to the unavailability of prior *O-D* trip tables, we examine the estimated *O-D* trip table with maps of the city including street network, Census population, and land uses and determined that the *O-D* trip table represents a reasonable estimate of travel patterns in the area with flows between zones corresponding to the sizes of zonal production and attraction potentials.

After the baseline production and attraction are obtained, the parameters of the trip distribution model need to be calibrated. In this study, gravity model is used as the trip distribution model and the commonly used Gamma function, which combined both exponential and inverse power functions, is used as the travel impedance function [see Eq. (2)]

$$f(\pi_{rs}) = \alpha \cdot \pi_{rs}^{-\beta} \cdot \exp(-\gamma \cdot \pi_{rs}), \quad (2)$$

where α and γ are greater than zero, and π_{rs}=measurement of travel impedance between zones r and s. The combined form of Gamma function provides additional parameters that can potentially increase the overall statistical fitness of the model. Calibra-

Table 1. Estimation of Specific Plan Trip Production and Attraction

Parcel ID	Land use	Unit	Number	Trip rate	PM total trip ends	PM entering (attraction)	PM exiting (production)
1	Service commercial	ksf[a]	26	2.59	68	29	39
1	Industrial	ksf	52	0.98	51	6	45
2	Service commercial	ksf	3	2.59	9	4	5
3	Service commercial	ksf	12	2.59	31	13	18
4	Office	ksf	13	1.72	22	3	19
5	Industrial	ksf	65	0.98	64	8	56
6	Service commercial	ksf	75	2.59	1.94	84	111
7	SFD	du[b]	5	1.01	5	3	2
8	Service commercial	ksf	26	2.59	68	29	39
9	Service commercial	ksf	102	2.59	263	113	150
10	Service commercial	ksf	18	2.59	47	20	27
11	Apartments	du	215	0.62	133	89	44

[a]ksf=1,000 ft^2.

[b]du=dwelling unit.

tion of a gravity model is typically carried out with an iterative process by changing the values of parameters until the model can replicate the observed trip length frequency distribution (TLFD), which identifies the proportions of overall trips made within different ranges of travel time (Ortuzar and Willumsen 1995). Because there is no observed TLFD data available, the case study identifies the travel time between a particular *O-D* pair from the corresponding cell in the network travel time matrix and estimate the existing TLFD by summarizing the number of trips made within a particular range of travel time. The values of the parameters α, β, and γ are 1.0002, 0.2073, and 0.0002 respectively.

In the cases when new development projects are expected in the study area, the additional number of trips generated to the area can be estimated with the trip generation rates published in *Trip generation* of Institute of Transportation Engineers (ITE 1997) to convert volumes of proposed land uses to numbers of trip end production and attraction. The ITE trip generation rates are used by planners and traffic engineers to study traffic impacts of land development. Using the ITE trip rate estimates provides an economical and reasonable estimate when planning resources are limited. Full "built-out" of the land use parcels within the specific plan area in St. Helena is estimated based on the city's general plan. ITE trip generation rates are applied to convert the land use volumes to numbers of total vehicle trip ends generated during the evening peak hour (see Table 1). The entering and exiting trip ends are used to estimate vehicle trip attraction and production respectively. Since no other potential development is expected elsewhere in the city, the additional trips produced from the attracted to TAZs in the specific plan area are added to the baseline production and attraction for the estimation of future "built-out" travel demand. Trip balancing is subsequently performed to ensure that the total number of production equals that of attraction. The St. Helena planning network is then revised according to the conceptual street design proposed in the specific plan. The calibrated gravity model is applied to the future production and attraction to forecast the future *O-D* trip table representing travel demand under the "built-out" land use and street design of the specific plan. Traffic assignment of the "built-out" *O-D* trip table is subsequently performed to forecast traffic volumes on Oak Avenue for analysis of level of service (LOS).

To facilitate analysis of level of services on the design street using standard methodology in *Highway capacity manual* 2000 (TRB 2000). Forecasts of link and intersection turning movement volumes are derived from the results of traffic assignment. The forecasted volumes together with geometries of the conceptual design are entered into capacity analysis software for estimation of control delay. The results of such a LOS analysis (e.g., Table 2) can be used to assist in the decision-making process of right-of-way and lane configurations.

Conclusions

A procedure has been developed to model network traffic for planning applications in small and medium-sized communities with limited planning resources. The proposed method is based on the theories and assumptions of conventional four-step travel demand models, but trip generation is substituted with a trip table derived from existing traffic counts to render a quick response approach that requires less data than the conventional approach. The proposed procedure is applied with data from a small community. An *O-D* trip table is estimated from traffic counts. The estimation process is demonstrated to be feasible as the results matched observed data with a satisfactory error bound. The traffic impacts of various scenarios of land use and network changes are promptly and effectively evaluated with the modeling approach. Crucial information for the decision-making of intersection design and right-of-way preservation can be provided with the modeling results.

A study of the properties of PFE *O-D* estimation has been conducted (Chen et al. 2005). The quality of traffic count data has a significant effect on the quality of a PFE estimated *O-D* trip table. It is determined that the selection of observed links (loca-

Table 2. Level of Service Analysis

Segment	Direction	Volume (Vehicles/h)	Time (s)	Speed (mi/h)	LOS
1	NB	175	22	29	A
	SB	256	35	19	B
2	NB	243	9	28	A
	SB	313	9	28	A
3	NB	354	40	13	D
	SB	326	41	12	D

tions of traffic counts) plays an important role in the *O-D* estimation problem, as each observation contributes differently to the quality of estimation. The quality of estimates can also be improved with the usage of more traffic counts. Care should be exercised when assembling traffic counts for *O-D* estimation to ensure that the traffic count locations are placed around the modeling area to intercept as many *O-D* pairs as possible. It is also recommended that the reasonableness of the estimated *O-D* be examined based on an understanding of the region's population, land use, and travel patterns, if no prior *O-D* trip table is available for the examination.

Based on the experience gained from the case study, the proposed approach is applicable for small to medium-sized communities with limited resources. In addition, since ITE trip generation rates and HCM are both utilized in the modeling process, the analysis scope and results are consistent with those of common traffic impact studies and other 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.

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