Evaluating Urban Downtown One-Way to Two-Way Street Conversion Using Multiple Resolution Simulation and Assignment Approach

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Abstract: There is a developing trend to change the flow configuration in urban downtown or central business districts (CBD) from one way to two way. However, it has been difficult to reasonably estimate the traffic flow resulting from the two-way conversion. This paper presents a multiple resolution simulation and assignment approach to estimate traffic and environmental impacts due to different flow configuration scenarios. It is based on the logical integration of an origin-destination (OD) matrix estimation method, a mesoscopic traffic simulation model, and a microscopic dynamic traffic assignment model. The dynamic traffic assignment model is employed in conjunction with a method to estimate dynamic OD demand from collected link and movement traffic counts to reassign the traffic onto the proposed two-way flow configurations. The reassigned traffic is then loaded into the microscopic simulation model to permit detailed analysis of traffic and environmental impacts. A case study based on the El Paso, Tex. CBD network is conducted to illustrate the performance of the proposed methodology. The application highlights the unique features in the methodological aspect and illustrates the considerable benefits resulting from the proposed MRSA framework. Possible drawbacks and benefits of the conversion are discussed.

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Introduction

The downtowns of many United States cities have been experiencing a decline in population in the last century primarily due to a phenomenon known as suburbanization or urban sprawl. Urban sprawl is rooted in the nation's 19th century industrial revolution, which attracted a vast amount of rural farmers in becoming industrial city dwellers. However, the overcrowded and unhealthy urban living conditions and the rapidly established high-speed expressway system eventually transformed the urban development framework to be dispersed and low density. Suburbanization can be generally described as the expansion of an urban area into the areas of countryside that surround it. Suburbanization is often characterized as: (1) leapfrog or scattered development; (2) commercial strip development; (3) low density; and (4) large expanses of single-use development (Ewing 1997). It is a widely held view that such an outward migration of residential and commercial activities is the culprit of the decline of the urban downtown (Ewing et al. 2003; Gillham 2002).

Many cities that were built before the prevalence of the automobile later converted their downtown streets to a one-way system because these cities generally had narrower streets and smaller blocks. One-way streets were thus an attempt to accommodate auto traffic in areas not built for autos. However, in the 1930s–1950s, many cities with wide streets and longer blocks typical of the postauto era still adopted the high-speed and high-capacity one-way street configuration (O'Toole 2005).

With city cores falling due to suburbanization, many cities started to incorporate the one-way to two-way conversions in their downtown revitalization programs. A short list of numerous proposed or implemented projects include cities like Albuquerque, N.M. (Tran, M., personal communication by Celia Veloz, March 2003), Tucson, Ariz. ("Rio Nuevo: A plea for patience" 2005; Tucson Department of Transportation 2004), Tampa, Fla. (Hunter Interests Inc. 2005), Alma, Mich. (Ripley 2005), Pittsburg, Kan. (City of Pittsburg 2005), and Austin, Tex. (Librach 2005).

Many planners and downtown business owners deem high-speed, high-capacity, one-way systems, although attractive for commuting, as detrimental if the goal is to promote work, shopping, and recreational activities downtown. The restricted accessibility of the one-way configuration is discouraging for tourists in finding and reaching points of interest. Two-way configurations instead are the key to creating a pedestrian-friendly environment and an improved transportation experience for downtown goers (Hunter Interests Inc. 2005; Jossi 1998; Tucson Department of Transportation 2004).

However, not everyone shares the same view and converting downtown one-way streets to two way has been an ongoing debate. Many existing reports document conflicting results and perspectives. For instance, one report shows positive feedback from

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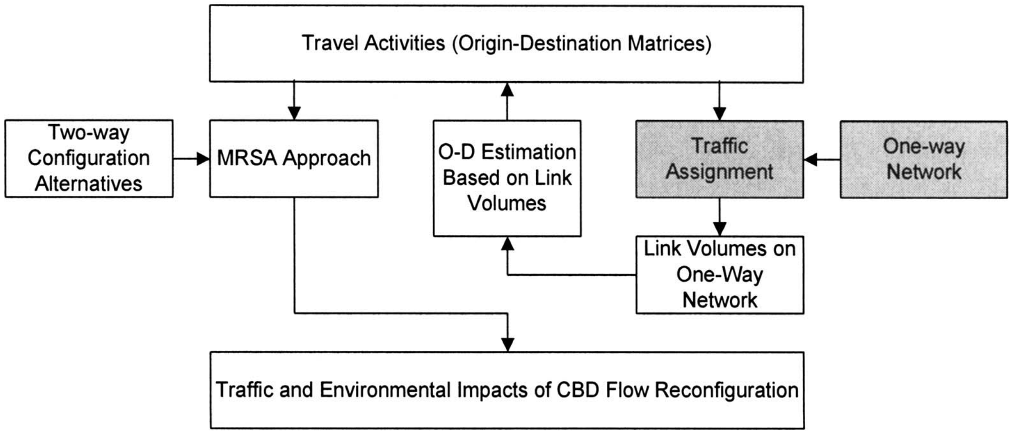

Fig. 1. CBD flow reconfiguration modeling concept (nonshaded areas are those explicitly addressed in modeling framework)

converted communities (Ripley 2005). On the other hand, another report discusses concerns relating to the decrease in traffic speed, increasing intersection delays, reduced curbside parking space and roadway capacity, increased potential pedestrian-vehicle conflicts, and the requirement for a significant financial investment (Levin 2002). Similarly, another report opposes the conversion and argues that the one-way configuration is superior to the two way by largely measurable criteria—safety, pollution, congestion, and effects on most local businesses (O'Toole 2005).

The main skepticism about the conversion is the belief that downtowns decline for many reasons other than congestion, and there is no consistent evidence showing that converting one-way to two-way streets will reverse this trend. It is also suspected that businesses that decided to leave downtown for the suburbs did so in part because downtowns were more congested than the suburbs, and the two-way configuration will create more congestion, eventually further aggravating the decline of downtowns (O'Toole 2005).

Although no immediate verdict can be sought for this ongoing debate, one thing to be certain of is that most existing traffic analyses conducted for estimating the traffic impact of the conversion could be questionable. Most prior studies use traffic data on the existing one-way configuration and apply certain assumptions or engineering judgment to estimate the new distributions of traffic flows, speeds, and delays on links in the proposed two-way configurations (Cardenas 2002; Hart 1998; Tran 2003). Such an estimation process is not reliable because the redistributed traffic flows result from the way that tripmakers choose new routes to reach their downtown destinations. Multiple factors affect how tripmakers choose new routes, depending on the available new routes and the traffic conditions along the routes. Additionally, the traffic conditions on these routes are also jointly affected by other tripmakers' route choices. Downtown tripmakers may eventually settle on certain routes after trial and error or learning the traffic conditions over time. The resultant traffic conditions characterize the traffic impact of the conversion. The entire process can also be described as the "demand/supply re-equilibration" process due to the conversion. Capturing the above equilibration process is important for reasonably estimating the traffic conditions on the converted network.

The objective of this study is to propose an intuitive and theoretically sound approach to estimate traffic and environmental impacts resulting from downtown traffic flow conversions. The proposed multiple resolution simulation and assignment (MRSA) approach entails a logical integration of two traffic simulation assignment methods with different traffic simulation resolutions and traffic assignment capabilities, as well as one origin-destination (OD) demand estimation procedure. The performance of the proposed methodology is illustrated through theoretical discussions and a case study. This study however, does not explicitly address the transit and pedestrian issues, nor does it try to answer the questions on whether downtown street conversions facilitate the effort of revitalization. Nonetheless, this paper is aimed at providing the foundation on which further related studies and discussions can be quantitatively and objectively carried out.

This paper is structured as follows. The next section discusses the concept of the MRSA methodology in conjunction with the background and details of comprising models. The modeling process is then presented in detail, followed by the results and discussion of applying the MRSA approach to the case study in El Paso, Tex.

MRSA Approach

The proposed MRSA framework is based on the assumption that a tripmaker's traveling activities remain unchanged regardless of the roadway traffic flow configurations. We consider this assumption to be reasonable because no evidence exists that the intensity and pattern of the existing commercial, government, or retail business land use pattern will significantly change in the short term solely due to the change of traffic flow configuration. Following this concept, the proposed research approach, as shown in Fig. 1, starts from estimating the travel demand (e.g., the OD information of the study area) using the link traffic counts from the study site. Once the OD information is established, we propose to use the dynamic traffic assignment (DTA) approach (e.g., DYNASMART-P) to assign the traffic on each alternative two-way configuration. The DTA approach used in this study is the time-dependent user equilibrium method. For each two-way configuration alternative, the assignment results are later loaded to a microscopic traffic simulation model (e.g., CORSIM) to assess the traffic and environmental impacts of each configuration scenario in detail.

The purpose of integrating the mesoscopic simulation-based DTA model and the microscopic simulation model is to take advantage of the complementary features of both models. Microscopic simulation models, such as CORSIM, with the capability of describing traffic and environmental impact in great detail,

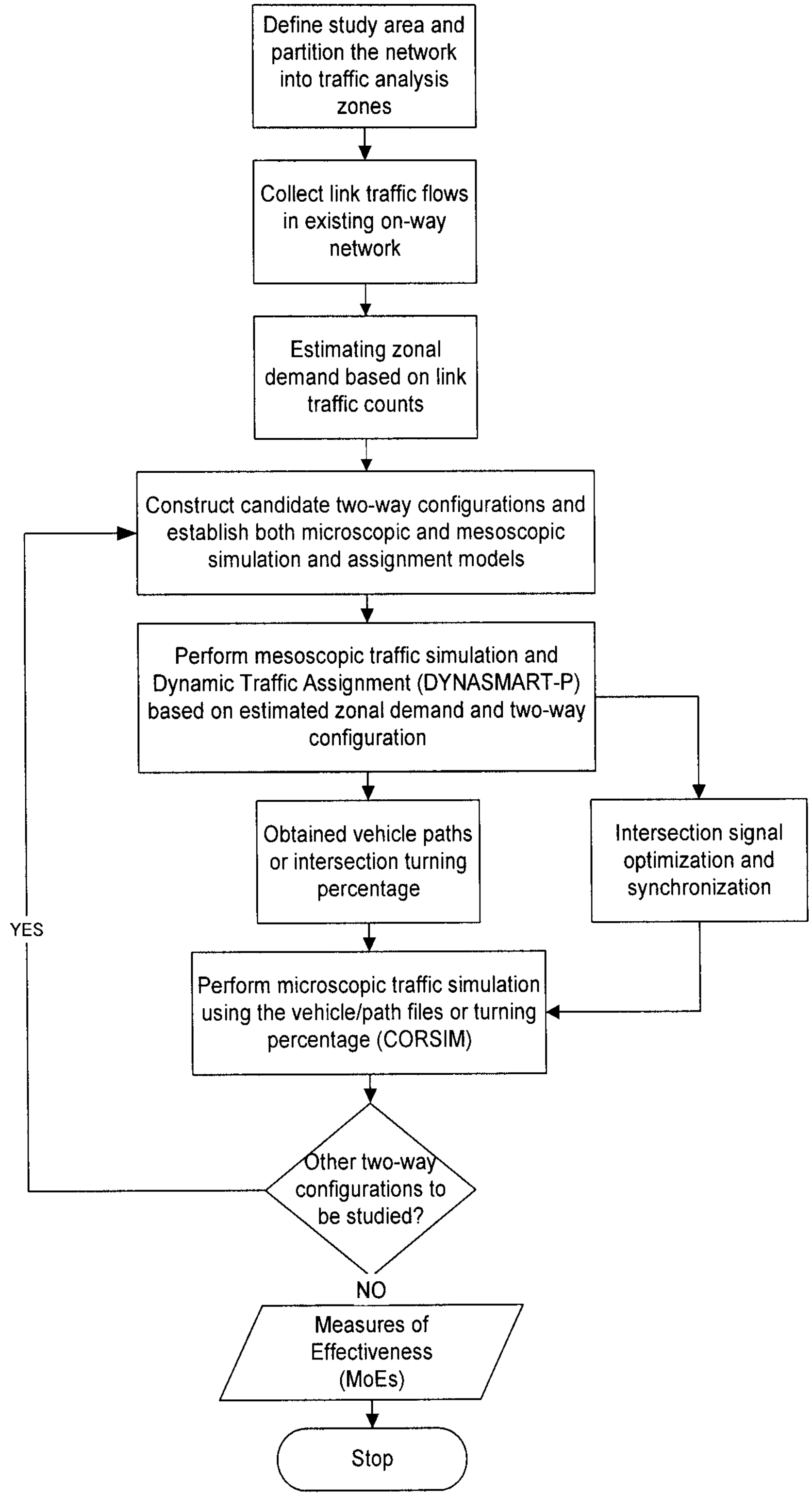

Fig. 2. Multiple resolution simulation and assignment framework

generally requires network entry volumes to be exogenous data specified by the user. This in turn limits its capabilities in capturing the redistributed traffic flow on the new roadway configuration. On the other hand, DYNASMART-P, a state-of-the-art DTA model, is suitable for assigning travel demand to the two-way alternative using the estimated OD data, but it generally gives travel time information without detailed traffic measures of effectiveness at link and intersection levels (e.g., delay per lane) or environmental impact (e.g., fuel consumptions, emission, etc.). In order to overcome the technical challenges in evaluating the traffic impact of central business district (CBD) flow reconfiguration, the proposed approach utilizes the models with different simulation resolutions and assignment capabilities in a complementary manner.

The operational procedure of the present framework is depicted in Fig. 2 and explained as follows. The first step of the procedure is to define the study areas into appropriate traffic analysis zones (TAZs). The TAZs commonly maintained by the metropolitan planning organization (MPO) may not be suitable for this type of study because the MPO-defined zones could be overly large so that the study site may be encompassed by only a limited numbers of TAZs. Without further disaggregating the zones, the excessive intrazone traffic may become problematic for modeling.

Given the redefined disaggregated zones, the corresponding time-dependent OD matrices need to be estimated based on the traffic counts surveyed from the links in the study area. The proposed estimation approach is a quadratic program with equilibrium constraints that considers adjusting the OD matrices with the objective of minimizing the deviations between the observed and estimated link counts and between the actual and historical OD matrices.

A mesoscopic simulation based dynamic traffic assignment model—DYNASMART-P—is then used to take the estimated time-dependent OD matrices to assign the zonal trips to a number of two-way configuration alternatives. Once the time-dependent user equilibrium is reached for each alternative, the resultant traffic information is further incorporated into the microscopic simulation model (CORSIM) to obtain detailed traffic flow and environmental impact statistics. This is accomplished by obtaining the resulting turning percentages from DYNASMART-P simulation and entering such information into the equivalent CORSIM simulation. During the process, an intersection signal optimization task is also carried out to ensure that the optimal signal timings subject to minimal pedestrian crossing times are in place with respect to different two-way configurations.

The interface between DYNASMART-P and CORSIM can be accomplished in two different ways. The first is to use the vehicle/path vehicle loading feature in CORSIM. In addition to specifying entry volumes at entry nodes, CORSIM allows a user to load vehicles via its designated vehicle and path files. Because DYNASMART-P is also a vehicle-based simulation assignment model, path-assignment vehicle simulation trajectory information can be easily converted to the required CORSIM format and then loaded into CORSIM using these input files. This step however requires the mapping between the node numbers in CORSIM and in DYNASMART-P. The second approach, a relatively easier approach, is to determine the intersection turning percentages when DYNASMART-P reaches the equilibrated flow, and then input such information into CORSIM. The intersection turning percentage can be generated from DYNASMART-P from postprocessing the simulation output files.

The above process is repeated for each flow configuration scenario or modification of traffic control strategies, such as removal of curb-side parking. In the following sections, brief introductions of DYNASMART-P and CORSIM are given separately, followed by the explanations of the methodology used for estimating the time-dependent zonal OD demand.

Mesoscopic Traffic Simulation and Assignment Model—DYNASMART-P

DYNASMART-P is a state-of-the-art dynamic network simulation and analysis tool. With sponsorship provided by Federal Highway Administration (FHWA) since 1995, DYNASMART-P has been recognized in both researh and application communities because of its superior network modeling capabilities (Chiu and Mahmassani 1998; Jayakrishnan et al. 1994; Mahmassani et al. 2000; Chiu and Mahmassani 2003; FHWA 2005; Mahmassani et al. 2003). Aiming to overcome several known restrictions of static tools used in prevalent practices, DYNASMART-P is an effective tool in application areas such as intelligent network designing, planning, evaluation, and traffic simulation. By modeling individual traveler's traveling adjustments that determine the evolution of traffic flows in a traffic network, DYNASMART-P simulates travelers aiming to achieve a connection of activities at different points/locations.

DYNASMART-P allows consideration of an expanded set of traveler activity measures, compared to both traditional static assignment models and traffic simulation tools. This is primarily due to: (1) richer representation of traveler behavior decisions at the discrete level than that of static assignment models; (2) explicit description of traffic processes and their time-varying properties; and (3) complete representation of the network elements, including signalization and other operational controls (FHWA 2005).

The key features of DYNASMART-P are briefly discussed as follows: Traffic generation is based on the specified zone-to-zone demand during each demand subinterval. Vehicles are generated on links specified to be "generation links." First, the total specified generation during a subinterval from each zone is calculated from the OD demand data, specifying the number of vehicles to be generated during each time step in each zone. When a vehicle is generated according to this rate, it is immediately assigned to a randomly selected generation link in the zone, thus splitting the generation equally among such links. Each vehicle's destination is determined based on the trip distribution fractions (calculated from the OD data). As each zone with trip ends has a specified destination node, the destination node of each vehicle is determined. Note that the specified destination node of a zone can be a virtual centroid connected via high-speed links to a few other nodes in the zone, or it can be a regular node.

At the time of generation, each vehicle could be randomly tagged to be equipped for information, based on the specified fraction of equipped drivers. An initial vehicle path could be assigned from the *k*-shortest paths stored after the loadup period or any paths externally specified in the data (e.g., paths corresponding to user equilibrium).

The vehicle movement during each time step is determined by the speed in the link resulting from the density at the end of the previous time step. All moving vehicles in a link move at the same speed during each time step, according to the speed-density relationship modified from the well known Greenshield's equation. A specified minimum speed at jam density ensures that the simulation does not "shut down" due to zero speeds. The relationship used is

$$\nu = \nu_0 + (\nu_f - \nu_0)\left(1 - k/k_{\text{jam}}\right)^{\alpha} \quad (1)$$

where ν_0=user-specified minimum (jam) speed; ν_f=free-flow speed of the highway segment; k=density; k_{jam}=density at the jam speed; and α=user-specified parameter.

Unlike in microscopic models, there is no simulation of lane-changing maneuvers or car following in DYNSMART-P. There is no platoon dispersion equation to model the headway variations among vehicles. Also, the vehicle positions are not constrained by vehicle lengths. However, the vehicle lengths are properly accounted for when the end-of-link queues are modeled, and highway intersection signal controls are properly modeled to represent intersection queuing and delays. These approaches are essential to keep the computations accurate and manageable.

Table 1. Primary Simulation Components in DYNASMART-P Model

Simulation mechanism (each simulation interval)	Basic functions
Vehicle generation	Generate vehicles from user-defined generation links based on the time-dependent OD table
Link pass	Update link speed and vehicle's position on the link
Node pass	Simulate traffic control features at network nodes and move node crossing vehicles
Travel time	Calculate link travel time based on moving time and queue waiting time
Flow constraints	Limit the maximum number of leave/enter vehicles (link outflow and inflow) based on the traffic flow model and intersection capacity
Intersection control	Quantify the capacity of signalized or unsignalized intersection controls within the current simulation interval
Freeway control	Model the ramp metering and dynamic message signs (DMS)
Left-turn movement	Calculate left-turn delay by adjusting capacity and saturation flow rate

In summary, the dynamic network loading process is achieved based on a series of simulation components that are triggered at each simulation interval. These basic simulation mechanisms are summarized in Table 1.

As shown in Fig. 3, the traffic assignment process involves the interplay of the simulation model and the time-dependent shortest path and flow redistribution component. During the iterative computational process, the time-dependent link travel time and intersection delays are input into the time-dependent k-shortest path algorithm. Based on the shortest path calculation results, the new flow distribution and routing policies are computed in a time-dependent traffic assignment procedure, and then input into the traffic simulator to assess the performance the assignment results. The process is repeated until the convergence criteria or the maximum numbers of iterations are reached.

Microscopic Traffic Simulation Model—CORSIM

The model, corridor simulation (CORSIM), was originally developed by FHWA in the 1960s and has undergone extensive upgrades and enhancements over time. CORSIM is used to evaluate improvement alternatives for freeways and surrounding surface streets, including lane-striping alternatives, impacts caused by lane closure or high-occupancy vehicles (HOVs), ramp metering design, and development of alternate incident management strategies. By far, CORSIM is the most widely used microscopic traffic simulation model in the United States and worldwide (Owen et al. 2000). CORSIM's general features include the following:

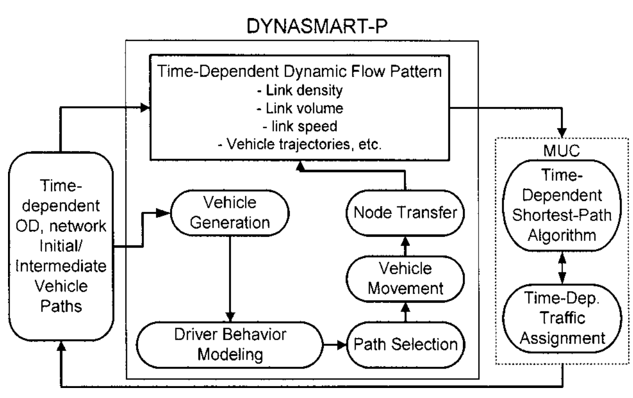

Fig. 3. General algorithm structure of DYNASMART-P model

1. Capability to model complicated geometric conditions, including combinations of through lanes and turning pockets, multilane freeway segments, and different types of on- and off-ramps;
2. Capability to simulate various traffic conditions, from modest demand to congested conditions, including flow during an incident, from queue buildup to recovery to normalcy;
3. Ability to simulate different types of traffic controls, including stop or yield signs, fixed timing, or actuated control at surface street intersections. Freeway ramp metering and HOV operation can also be simulated;
4. Ability to account for interactions between freeways and surface streets so that spill back and spillover can be modeled effectively;
5. Capability to model time-varying traffic and control conditions; and
6. Provision of detailed traffic and emission statistics, including link traffic volumes by lane, total or average travel time, total or average traveling distance, intersection delay, etc.

Origin-Destination Zonal Demand Estimation Based on Link Traffic Counts

Estimating the OD zonal demand plays an important part in the proposed research framework since we need to employ zonal demand information to perform time-dependent traffic assignment on the two-way configuration. However, for the study area, the zones need to be defined in a finer resolution; as such, the OD demand for these zones needs to be estimated based on the observed link counts.

Substantial research has been devoted to the dynamic demand estimation problem over the past 20 years. An important research direction is to improve the representation capability of the estimation model to adequately describe dynamic traffic and behavioral processes in networks. Accordingly, existing models can be grouped into two classes (Chang and Tao 1999): DTA based and non-DTA based, depending on whether a DTA component is incorporated into the estimation process. Early models, for example, were proposed to estimate time-dependent OD flows on individual components, such as a single intersection or a freeway facility (Cremer and Keller 1987, 1981). These models seek to estimate unknown dynamic OD split fractions based on the entry and exit flow measurements, under the simplifying assumption of constant link travel time. In order to establish a more realistic measurement equation, researchers have further used nonlinear macroscopic traffic relations to compute segment density, speed, and travel time (Chang and Wu 1994). Other research has proposed a generalized least-squares (GLS) estimator for time-varying OD demand based on a simplified assignment model that generates dynamic link flow proportions for a traffic network (Cascetta et al. 1993). To maintain internal consistency between the demand estimation problem and the dynamic traffic assignment problem, additional research has proposed a bilevel generalized least-squares optimization model to estimate dynamic OD demand, while a simulation-based DTA program was used to iteratively generate link flow proportions (Tavana and Mahmassani 2001) and (Tavana 2001). This framework was further extended to incorporate historical static demand information and multiday traffic measurements (Zhou et al. 2003; Mahmassani and Zhou 2005).

This research adapts the bilevel iterative OD estimation framework proposed by Zhou et al. (2003). Considering a vehicular traffic network with multiple origins $i \in I$ and destinations $j \in J$, as well as a set of nodes connected by a set of directed links. Let l denote the subscript for links with traffic measurements, $l \in L$. The analysis period of interest, is discretized into departure time intervals $\tau = 1, 2, \ldots$,time horizon for demand (Td), and the time-dependent OD trip desires are expressed as the number of vehicle trips $d(i,j,\tau)$, traveling from origin zone i to destination zone j in departure time interval $\tau \forall i \in I$, $j \in J$, and $\tau = 1, 2, \ldots$Td. In this study, measured link flow $c(l,t)$ is available on link $l \in L$ during observation interval $t = 1, 2, \ldots$,time horizon for link counts (Tc).

Given a traffic network with link counts and a target demand matrix, the dynamic traffic OD demand estimation problem is to find a consistent dynamic OD demand matrix that minimizes first the deviations between estimated and observed link flows, and second the deviations between estimated and target demand. Essentially, the dynamic OD estimation procedure aims to identify the number of trips for each OD pair in a spatial dimension, and for each departure time interval in a temporal dimension.

Eq. (2) shows the first type of deviations, by using estimated link proportions to map dynamic OD demand to time-varying link flows

$$c_{(l,t)} = \sum_{i,j,\tau} \hat{p}_{(l,t),(i,j,\tau)} \cdot d_{(i,j,\tau)} + \epsilon_{(l,t)} \tag{2}$$

where $\hat{p}_{(l,t),(i,j,\tau)}$=estimated link-flow proportion based on a DTA program, i.e., the proportion of vehicular demand flows from origin i to destination j, starting their trips during departure interval τ, contributing to the flow on link l during observation interval t, $\epsilon(l,t)$=combined error term in estimation of traffic flow on link l during observation interval t.

Specifically, the combined error term $\epsilon(l,t)$ includes the following error sources:

- Model assumption errors related to linearity in link-flow proportion;
- Estimation errors related to simulated link-flow proportions;
- Sensor errors (i.e., identification errors) related to link count $c(l,t)$; and
- Aggregation errors related to time-varying OD demand flows.

If a historical static demand table is available for the entire study horizon, then the second objective function can be explicitly written as the difference between the static demand and the sum of dynamic demand over the study period, as shown in Eq. (3)

$$g_{(i,j)} = \sum_{\tau} d_{(i,j,\tau)} + \eta_{(i,j)} \tag{3}$$

where $\eta(i,j)$=combined error term in estimation of total traffic demand during period of interest from zone i to zone j.

A bilevel dynamic OD estimation formulation is used in order to integrate the dynamic traffic assignment constraint. Specifically, the upper-level problem seeks to estimate the dynamic OD trip desires based on given link counts and link-flow proportions, subject to non-negativity constraints for demand variables. The lower-level problem is a dynamic traffic assignment problem, which is solved by a DTA simulation-assignment program DYNASMART-P in this study. The DTA problem can be also considered as a complex nonlinear constraint that generates the link-flow proportions with a dynamic OD trip table calculated from the upper level.

The weights w and $(1-w)$ in the combined deviations could be interpreted as the decision maker's relative preference or importance belief for the different objectives; they could also be considered as the dispersion scales for the first and second error terms in the ordinary least-squares estimation procedure

$$\min Z = w \sum_{l,t} \left[\sum_{i,j,\tau} \hat{p}_{(l,t),(i,j,\tau)} \cdot d_{(i,j,\tau)} - c_{(l,t)} \right]^2 + (1-w) \sum_{i,j} \left[\sum_{\tau} d_{(i,j,\tau)} - g_{(i,j)} \right]^2 \tag{4}$$

subject to

$$[\hat{p}_{(l,t),(i,j,\tau)}] = \text{DTA}([d_{(i,j,\tau)}])$$

$$d_{(i,j,\tau)} \geq 0, \quad \forall\, i,j,\tau$$

where w=positive weight; $\hat{P}$=assignment (D) from DTA, matrix of link-flow proportions, consisting of elements $\hat{p}_{(l,t),(i,j,\tau)}$; and D=vector of OD demand flows, consisting of elements $d(i,j,\tau)$. If a time-dependent demand matrix is available a priori, the above objective function Eq. (4) can be expressed as Eq. (5), where $g_{(i,j)}$ is extended to $g_{(i,j,\tau)}$ for each departure time interval

$$\min Z = w \sum_{l,t} \left[\sum_{i,j,\tau} \hat{p}_{(l,t),(i,j,\tau)} \cdot d_{(i,j,\tau)} - c_{(l,t)} \right]^2 + (1-w) \sum_{i,j,\tau} [d_{(i,j,\tau)} - g_{(i,j,\tau)}]^2 \tag{5}$$

The iterative solution algorithm for the proposed bilevel programming problem is briefly described in the following steps:

1. (Initialization) $k=0$. Start from an initial guess of the traffic demand matrix D_0, obtain link-flow proportions $\hat{P}_0$ from the DTA simulator;
2. (Optimization) Substituting link-flow proportions $\hat{P}_k$, solve the upper level OD estimation problem to obtain demand D_k;
3. (Simulation) Using demand D_k, run the DTA simulator to generate new link-flow proportions $\hat{P}_{k+1}$;
4. (Evaluation) Calculate the deviation between simulated link flows and observed link counts, and calculate the deviation between estimated demand D_k and target demand; and
5. (Convergence test) If the convergence criterion is satisfied (when estimated demand is stable or no significant improvement is possible in the overall objective), stop; otherwise $k=k+1$ and go to Step 2.

Given a subset of links with archived link flow observations, a critical question is how to identify the demand dynamics using limited information, in particular, how to obtain a unique solution

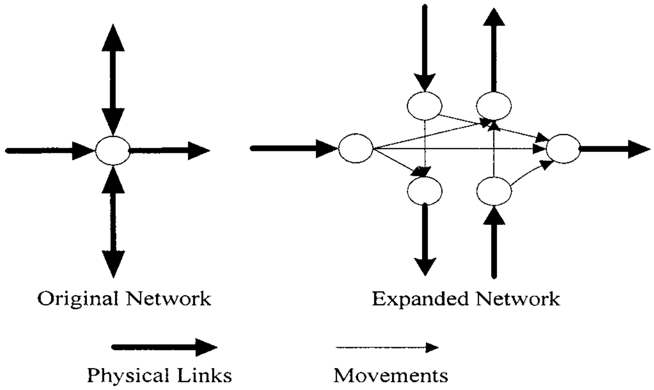

Fig. 4. Original network structure versus expanded network structure with link-to-link movements

for the above ordinary least-square formulation. This requires that the number of unknown variables (time-dependent OD demand flows) should be not greater than the number of link observations plus the number of OD pairs in the static demand matrix, as shown in Inequality (6)

$$|L| \times T_c + |I| \times |J| \geq |I| \times |J| \times T_d \qquad (6)$$

If the above system identification condition cannot be satisfied, a simple remedy is to increase the length of departure time intervals so as to reduce the number of unknown decision variables, but this demand aggregation scheme might undermine the capability of modeling OD demand dynamics. The second approach is to shorten the length of observation time intervals to increase the number of observations. However, a short observation time interval would increase the possibility of linear correlation in the link flow matrix, which makes the estimation result unstable.

To enhance the system identifiability of the OD demand estimation problem in this study, we can view a turning movement as a generalized link. A sample original network representation for an intersection with a one-way street from left to right is plotted in Fig. 4, together with the corresponding expanded network representation with movements as generalized links. In this study, turning movement counts at each intersection are converted to the generalized link counts accordingly. It should be noted that counts on a link are equal to the total counts of all the incoming movements to its upstream node and the total counts of all outgoing movements from its downstream node, indicating that the movement counts could be correlated with adjacent link flows. Nonetheless, the added information from movement measurements can still significantly enhance the overall system observability and make the estimation process rely less on the quality of the original OD demand.

Another important issue in OD demand estimation is how to determine the weighting factor w. It is possible to obtain the least-squares estimate of the weight value through linear regression. However, in planning analysis, it is more desirable to incorporate the planners' knowledge and experience in the estimation process, thus reflecting different degrees of confidence in the different sources of information. Furthermore, planners might like to adjust their preferences progressively as they develop better understanding of the problem. For these reasons, an interactive approach is presented to determine the weight for the above biobjective problem, consisting of the following two steps. A representative subset of nondominated solutions is first generated by varying the weight, and then the decision maker can determine

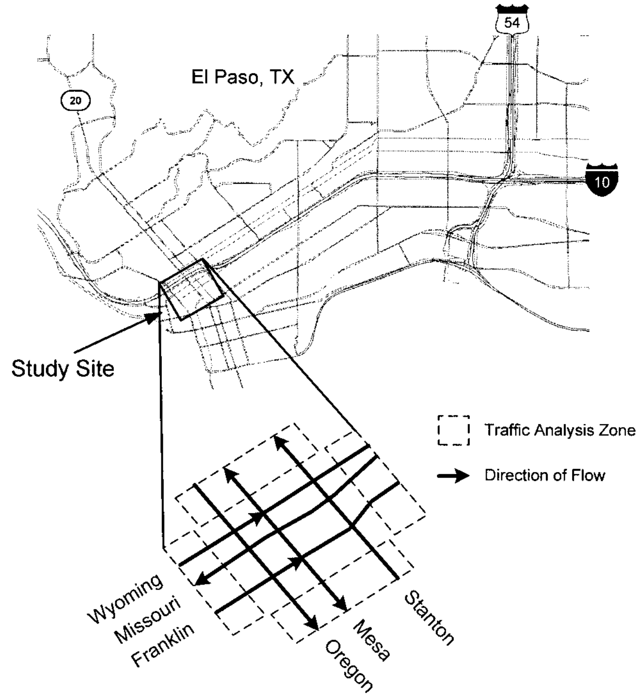

Fig. 5. Study network (downtown CBD, El Paso, Tex.)

the weight that results in the best compromised solution based on the criterion of minimum distance from the ideal point, as commonly used in the multiobjective programming field. Planners can define the goal f_1 and f_2 as the maximum possible deviation for the first and the second objectives, and then the goals for both objectives make up an ideal point $f^* = (f_1, f_2)$ or a utopia point. The best compromise solution is the one with minimum distance from the ideal point.

Case Study Modeling Procedures

The City of El Paso, a western Texas city located on the United States–Mexico border, has been considering the conversion of existing downtown one-way roadways to two way. Significant numbers of retail shops, museums, and office buildings are located in the downtown area in close proximity to the border port of entries. It is postulated that converting several major arterials from one way to two way may help revitalize the downtown area by attracting more El Paso and Juarez, Mexico residents to engage in commercial and social activities in downtown El Paso. However, like other cities, this proposal is deemed potentially controversial. A thorough and rigorous engineering analysis is hence needed.

The first step of applying the proposed modeling approach to this project is to define the project site. The CBD network of interest consists of nine intersections which are intersected by six major downtown streets. The boundary of the study site is defined as the 12 intersections surrounding the study site (see Fig. 5). The existing network flow configuration, denoted as scenario DN, is described as follows:

- Mesa Street—two way, two lanes in each direction with curb-side parking on both sides;
- Stanton Street—one-way heading southbound, three lanes with curb-side parking on both sides;

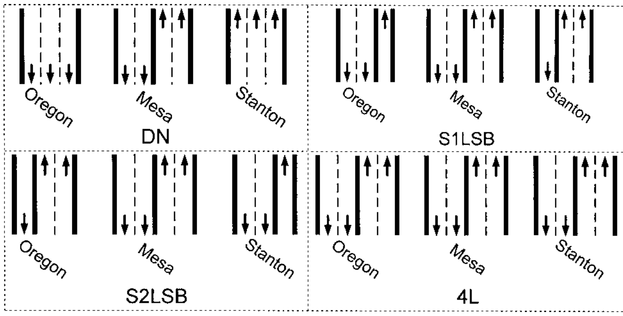

Fig. 6. CBD low configuration alternatives

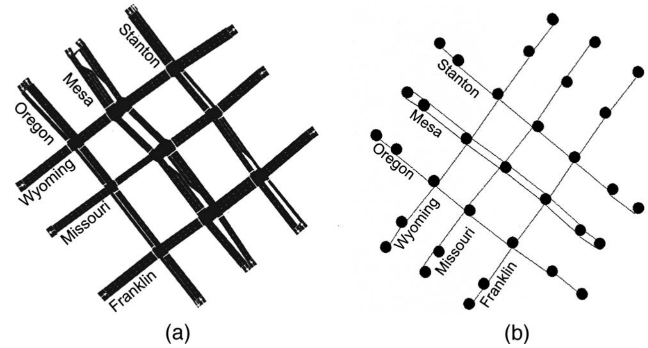

Fig. 7. Network represented in (a) CORSIM; (b) DYNASMART-P

- Oregon Street—one-way heading northbound, three lanes with curb-side parking on both sides;
- Wyoming Street—one way eastbound, three lanes with curb-side parking on both sides;
- Missouri Street—one way westbound, three lanes with curb-side parking on both sides; and
- Franklin—one way eastbound, three lanes with curb-side parking on both sides.

There were several alternatives considered by the City and researchers. The first proposed two-way configuration scenario, denoted as S1LSB (Stanton 1 Lane Southbound), converts both Stanton and Oregon into two-way streets. Both Stanton Street and Oregon Street have three lanes total with two lanes assigned to the northbound and southbound traffic, respectively, and traffic on Wyoming, Missouri, and Franklin remains one way. The second configuration, called S2LSB (Stanton 2 Lane Southbound) converts Stanton Street and Oregon Street by assigning two of the three lanes to southbound and northbound traffic, respectively.

The third flow configuration (4*L*) alternative configures both Stanton Street and Oregon Street to have two lanes in both directions. In order to have this scenario satisfy geometric requirements, curbside parking has to be prohibited either permanently or during peak hours in order to accommodate an extra lane, thus allowing for the two lanes in each direction. The forth alternative configuration continuous left-turn lane (CLTL) constitutes one lane in each direction and a CLTL at the center (see Fig. 6). It is noted that Mesa Street remains a two-way street and Wyoming, Missouri, and Franklin streets remain as one way in all alternative configurations, for the city wants to start with limited scope conversion due to the consideration of construction costs.

Traffic counts were taken at each of the nine intersections and at the 12 boundary intersections during a morning peak hour in October 2003. The intersection traffic counts were categorized by turning movements, and link traffic counts were later calculated by aggregating the turning-movement-based traffic counts. The traffic data were then organized in the format compatible with the previously discussed OD estimation model. The study site was then coded into both CORSIM and DYNASMART-P as shown in Fig. 7. Detailed geometric and signal data were obtained from the city and then input into the CORSIM model. Signal data are need for DYNASMART-P modeling, and a scheme of 12 TAZ was defined on which the OD demand was estimated based on the proposed OD estimation method from the observed link counts. It is noted that although the El Paso MPO maintains a travel demand model (TDM) that defines and estimates the OD data for the downtown area, the study site of interest was encompassed by only three zones. Using three zones to estimate and model traffic demand does not provide the level of zonal details that is required by this study. Thus, further disaggregating the study site into 12 zones became necessary.

Once the OD demand matrix was estimated, it was then utilized for all the flow configuration scenarios and each alternative was separately coded into CORSIM and DYNASMART-P. For each scenario, DYNASMART-P was used to assign the OD demand into the network over the 1 h simulation and assignment period. At this stage, the signal cycle length and phasing at the nine intersections in the study site were also optimized with consideration of the minimal green time for pedestrians. Once equilibrium was reached, the traffic turning movement percentages were recorded for each 10 min interval. The data that were then transferred into the CORSIM model consisted of the entry volumes at the 12 boundary intersections that were obtained from the OD demand matrices, optimal signal settings, and intersection turning percentages. The CORSIM simulation period was also set at 1 h over which the traffic and environmental statistics were collected. Moreover, it should be noted that the speed limits of each streets in the study network remain unchanged although it could also be optimized. Speed limits are usually determined based on the stopping distance that exists between two intersections. In the downtown setting, considering short street blocks and pedestrian crossing, keeping the street limit unchanged is a reasonable assumption and generally accepted by the city.

Flow Configuration Alternative Evaluation Results

Based on the CORSIM simulation results, it is found that all the two-way configurations lead to approximately 2–16% lower total vehicle distance traveled (VDT) compared to the existing network, as shown in Table 2. This finding could be attributed to drivers traveling a shorter distance to reach their destinations due to increased accessibility permitted by the two-way configurations. It is also noted that the 4*L* configuration exhibits a distinctly lower VDT compared with all other one-way or two-way configurations [16.5% lower than the benchmark do nothing (DN) scenario]. The 4*L* scenario provides the maximal capacity on the proposed reconfigured streets (Stanton and Oregon). After re-equilibrating the traveling demand based on the 4*L* configuration, it is found that the reconfigured Stanton and Oregon Streets accommodate higher traffic at satisfactory level of service (LOS), which entices drivers to reach their destinations by utilizing said streets, obviously the shorter routes to the tripmakers' destinations. On the other hand, the remaining two-way configurations with reduced capacity in one direction are likely to create congestion on the one-lane direction, thus forcing tripmakers to utilize other less congested albeit longer routes. Unsurprisingly, the ex-

Table 2. Traffic and Environmental Results (Parenthesis Represents Percent Improvement upon Worst-Case Benchmark)

Scenarios	Vehicle distance traveled (km) (% to benchmark)	Average speed (km/h) (% to benchmark)	Average move time (s) (% to benchmark)	Average delay time (s) (% to benchmark)	Fuel consumption (liters) (% to benchmark)
DN	281.6 (0)	18.6 (17.2)	26 (0.0)	41 (21.1)	132.5 (0.0)
S1LSB	257.6 (8.4)	15.8 (0.0)	24 (7.3)	49 (5.8)	78.7 (42.8)
S2LSB	272.0 (3.5)	16.0 (1.1)	26 (0.0)	51 (2.0)	124.9 (5.7)
4L	232.5 (16.5)	19.0 (21.0)	24 (7.3)	37 (28.9)	64.4 (51.4)
CLTL	275.2 (2.2)	15.8 (0.0)	26 (0.0)	52 (0.0)	87.1 (34.3)

isting DN configuration results in the highest VDT because of its restricted accessibility and the tripmakers need to drive through a longer route to reach their destinations.

In comparing the average traveling speed in each configuration, the DN configuration exhibits a good performance at 18.7 km/h, outperforming most of the two-way configurations. The worst-case benchmark in this regard is the S1LSB configuration with an average speed of 15.9 km/h. The two-way configuration generally results in a 17% speed reduction, which is rather consistent with the observations reported in prior studies (Levin 2002). Simulation results also show that noticeable delay and queues appear on the one-lane link in the S2LSB, S1LSB, and the CLTL configurations, likely to be the main contributing factor for the speed reduction. Nonetheless, for all configurations studied, the four-lane (4*L*) configuration appears to have the highest average speed at 19.0 km/h, a 21% improvement over the benchmark S1LSB. The increased capacity on Stanton and Oregon Streets (two lanes in each direction) contributes to shorter traveling distances and smoother traffic flow, and thus is considered the main contributing factor for speed improvement.

The move time for all scenarios, including the DN scenario, ranges from 24 to 26 s. However, the average delay time varies considerably, ranging from 37 s (4*L* configuration) to 52 s (CLTL configuration). It is clear that even after optimizing the signal settings, all the two-way configurations, with the exception of the 4*L* scenario, result in a higher intersection delay time than the DN configuration. Two-way configurations create more intersection conflicting movements than the one-way configuration, leading to the need to have more signal phases and more startup lost time, and likely more delays. Furthermore, all two-way configurations except the 4*L* scenario have relatively higher VDT, implying that vehicles traverse longer distances and likely more intersections. As such, tripmakers are likely to experience higher intersection delays. Nonetheless, compared to all scenarios, the 4*L* configuration appears to remain outstanding in this regard, which is likely to be attributed to a lower VDT and higher link capacity.

From Table 2, it can also be noted that the total fuel consumption follows the similar pattern of VDT across the different configurations. Fuel consumption is generally jointly affected by both VDT and congestion levels. Since the DN configuration permits the highest VDT by a distant margin compared to all the two-way configurations, the DN configuration obviously results in the highest fuel consumption. Although it is rather clear that the 4*L* configuration stands out as a desirable configuration, it should be noted that the curb-side parking has to be removed either during the peak hour or permanently, requiring additional investigation in parking need and public opinion analysis.

In summary, the MRSA analysis results indicate that different two-way configurations could lead to varying degrees of traffic impacts. Reduced VDT and speed and increased intersection delays could be generally observed in the majority of the proposed two-way configurations, which appear to be rather consistent with results reported in the literature. Nonetheless, the findings also suggest that the two-way configuration could be desirable in all considered criteria if carefully designed and planned. Such a possibility is characterized and quantified through the proposed MRSA approach.

Concluding Remarks

Although it seems to be a commonly held view that converting the high-speed and high-capacity one-way downtown streets to two way could be important for a downtown revitalization program, the existing methodology of estimating the traffic and environmental impacts on the new configuration has relied on extensive engineering judgment and assumptions. This paper aims to improve the traffic modeling aspect by proposing an integrated multiple resolution simulation and assignment framework that carefully integrates the OD estimation, dynamic traffic assignment, and microscopic simulation approaches. This approach is based on two intuitive postulations: (1) downtown land use patterns and tripmakers' activity destinations do not drastically change due to the conversion in the short term; and (2) downtown tripmakers will adapt to the conversion and seek the minimal-travel-time routes to reach their activity destinations. It is therefore noted that the proposed approach is suitable for short- to midterm applications, which requires reevaluation when it is believed that the downtown land use pattern or traveling activities are significantly changed.

Based on such a modeling foundation, the simulation-based dynamic traffic assignment approach allows traffic flow to be reasonably reflected on various new proposed configurations without needing ad hoc assumptions or human judgment. Other aspects of traffic impact (e.g., parking, transit, and safety), although not explicitly discussed, can be effectively addressed using the proposed approach by incorporating appropriate traffic assignment and microscopic simulation models. For example, CORSIM reflects the impact of curb-side parking in the simulation. Another microscopic simulation model, VISSIM, explicitly models and simulates transit systems.

The case study presented highlights the possible drawbacks and benefits of the traffic flow conversion and finds that two-way configurations do not necessarily bring forth desirable traffic performance. Among all proposed configurations, many of them do not necessarily outperform the existing one-way configuration. However, it is also shown that if carefully analyzed and designed, opportunities exist in order to make a two-way configuration a desirable option. Adequate capacities for both directions of the converted streets are needed and parking may need to be prohibited either permanently or during peak hours if capacity is not sufficient, although doing so requires a careful review of parking and public opinion issues.

Revitalizing an urban downtown is a great challenge that requires a well-planned and multifaceted program that addresses engineering, business, and aesthetic streetscaping issues. The debate on how two-way streets impact downtown revitalization may continue, but one thing to be certain of is that without a rigorous traffic impact study approach, the planners and downtown communities may always have to hold their breath on what may actually happen after the conversion.

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Notation

The following symbols are used in this paper:

$c(l,t)$ = measured link flow, available on link $l \in L$ during observation interval $t = 1, 2, \ldots, \text{Tc}$;
D = vector of OD demand flows, consisting of elements $d(i,j,\tau)$;
$d(i,j,\tau)$ = number of vehicle trips traveling from zone i to zone j in departure time interval $\tau \forall i \in I$, $j \in J$ and $\tau = 1, 2, \ldots \text{Td}$;
$g_{(i,j)}$ = number of trips from origin i to destination j in initial static OD matrix;
$g_{(i,j,\tau)}$ = number of trips from origin i to destination j at departure time τ in initial time-dependent OD matrix;
k = density;
k_{jam} = density at jam speed;
$\hat{P}$ = matrix of link-flow proportions, consisting of elements $\hat{p}(l,t)(i,j,\tau)$;
$\hat{p}(l,t)(i,j,\tau)$ = estimated link-flow proportion based on DTA program, i.e., proportion of vehicular demand flows from origin i to destination j, starting their trips during departure interval τ, contributing to flow on link l during observation interval t;
Z = value of objective function of model;
α = user-specified parameter;
$\epsilon(l,t)$ = combined error term in estimation of traffic flow on link l during observation interval t;
ν_f = free-flow speed of highway segment;
ν_0 = user-specified minimum (jam) speed; and
$\eta(i,j)$ = combined error term in estimation of total traffic demand during period of interest from zone i to zone j.

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