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A novel approach to model university student travel demand

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Abstract

Universities with large student enrollments often constitute special generators and contribute substantially to a region's travel demand. Universities are not only large in size, but also unique in nature because travel patterns of university students are substantially different from those of the general population. Student travel patterns are dictated by class schedules, part-time work arrangements, and unique living arrangements. Despite the recognition of the unique travel characteristics of university students, there is a dearth of research on the development of operational frameworks for modeling university travel demand. This study aims to fill this gap by proposing a comprehensive framework to model travel demand associated with a large university. The framework has several unique features that are specific to a university, such as the special treatment of intra-campus travel and the sensitivity of travel mode to parking infrastructure on campus. The framework is applied to two major (adjacent) universities in the city of Albuquerque, New Mexico. The framework was found to perform very well in replicating the travel patterns of the university population classified by affiliation (student, faculty and staff), education level (undergraduate, graduate), and living arrangement (on-campus, off-campus). Implementation of the framework was done in an open source coding platform (Python) to facilitate seamless integration with the existing regional travel demand model.

Keywords: university student travel; university submodel; special generator; travel demand modeling; model application and implementation

1. Introduction

Universities with large student enrollment account for a significant portion of travel generated in a region and are often treated as special generators in regional travel demand models. However, the accurate representation and modeling of university travel demand has proven to be a challenge because most household travel surveys do not

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include sufficient samples of college students (and faculty/staff) to accurately quantify their travel characteristics. University students are usually under-represented in household travel surveys because they are a hard-to-reach population; many are transient in their residential arrangement, live on campus in group quarters, do not have landline telephones, and are not likely to respond to long intrusive travel surveys – the results of which are unlikely to impact them (Behrens et al., 2008; Khattak et al., 2011; Volosin et al., 2014; Wang et al., 2012).

Many metropolitan planning organizations (MPOs) have incorporated special generator submodels to account for such entities as large stadiums, airports, freight terminals, and retail or employment centers. However, they have not been able to incorporate university special generator submodels because of the lack of data and modeling frameworks that can adequately represent their travel behavior. In addition to metropolitan planning organizations, universities themselves may be interested in understanding travel demand patterns so that they can better plan and price parking infrastructure, introduce services that promote sustainable transport mode usage, and reduce congestion in and around the campus.

The importance of university-generated travel in influencing overall regional travel patterns has been well documented (e.g., Tolley, 1996). As a result, university travel surveys are being increasingly conducted in metropolitan areas and universities around the United States. Rodriguez and Joo (2004) used data from a travel survey conducted at University of North Carolina-Chapel Hill to study the relationship between commute mode choice and the built environment (for university subpopulations). Eom et al. (2009) used survey data collected at North Carolina State University to analyze activity-travel patterns of different university population segments. They find that undergraduate students and on-campus residents engage in more activities compared to off-campus residents and graduate students. Shannon et al. (2006) analyzed commuting patterns of staff and students at The University of Western Australia to understand factors that influence university travel mode shares and device policies to promote sustainable transport mode use. Khattak et al. (2011) analyzed travel patterns of students from four universities (two urban and two rural) in Virginia. They report that travel characteristics of students are indeed quite different from those of the general population. They find that students in rural colleges walk more than their urban counterparts and that university students depict a unique time of day distribution of travel with travel clustered towards the middle of the day and after 6 PM. Wang et al. (2012) analyzed the same data and found that students living on or near campus are more likely to use non-motorized modes.

Travel surveys have also been conducted at Ohio State University and the University of California at Davis. The data collected at Ohio State University has been used to analyze commute mode shares (Akar et al., 2012) and understand student and faculty/staff attitudes towards different modes. Numgung and Akar (2014) used the same data to identify the influence of built environment and attitudinal variables on the use of public transit as a commute mode. In the most recent travel survey at the University of California at Davis, it was found that 52 percent of the university population used non-motorized modes to travel to and from campus – consistent with the heavy bicycle emphasis in Davis (Popovich, 2014).

Universities themselves are exploring solutions to reducing the carbon footprint associated with university-generated travel demand, while also exploring ways to more efficiently utilize scarce resources and developable land (Poinsatte and Toor, 1999). Several studies recognize that limited parking availability influences travel and is of considerable concern in large universities with limited land (Alshuwaikhat and Abubakar, 2008; Balsas, 2003; Shang et al., 2007). Barata et al. (2011) studied parking supply and demand patterns at the University of Coimbra in Portugal and found that parking on campus is under-priced and hence over-utilized. Similarly Prolux et al. (2014) used data from a travel survey conducted at the University of California at Berkeley to identify strategies to reduce automobile mode share; they conclude that parking pricing strategies should be combined with other strategies such as transit subsidies to achieve significant mode shift.

Large universities are often spread over many acres of land, and hence generate a considerable amount of intra-university or intra-campus travel where faculty, staff, students, and visitors move between buildings, facilities, and grounds on campus – often by non-motorized modes. It is therefore important to distinguish between intra-campus travel and non-intra-campus travel in the context of university travel demand models.

Even the limited body of literature on university population travel characteristics provides ample evidence that university travel is unique and should be modeled through a special model specification. However, there are virtually no operational university model systems documented in the published literature; although it is likely that some four-step travel demand models include special generator model components applied to large universities, the models are likely to be rudimentary and inadequate in truly reflecting university population travel patterns because of the lack of data to estimate and validate such model systems. In the absence of such models, it is very difficult to accurately reflect the influence of university travel demand on overall regional travel patterns, and devise policies that mitigate any adverse impacts of university travel demand on the transport network.

This paper is intended to fill this critical gap by presenting a comprehensive university travel demand modeling framework that has been fully developed, specified, and implemented in two major metropolitan regions of the country, namely, the Greater Phoenix metropolitan region (where Arizona State University is a large university of interest) and the Albuquerque metropolitan area in New Mexico (where University of New Mexico and Central New Mexico Community College are large institutions of higher education). The operational model system has been implemented in an open source coding platform (Python) for ease of integration with the main regional travel demand model system in these respective regions.

The remainder of this paper is organized as follows. The next section presents a detailed description of the university modeling framework. The third section describes the travel data collected through a travel survey administered to the university population at Arizona State University in the Greater Phoenix region. The fourth section presents a case study describing the implementation of the modeling framework for the Albuquerque metropolitan area. The fifth section presents the results of sensitivity analysis exercises carried out on the university submodel. The final section provides concluding remarks and directions for further research.

2. A university travel demand modeling framework

The framework presented in this paper is aimed at estimating daily travel demand associated with a large university due to travel to and from campus undertaken by faculty, staff, and students. The framework does not account for commercial travel, non-personal travel demand, and visitor travel as these trip purpose categories do not have a substantive representation in the context of university (daily) travel demand. Special event travel is a category of much interest, especially in light of sporting events in a university; efforts are currently underway to include this category in the framework. Findings from the literature cited, coupled with information from the comprehensive travel survey conducted at Arizona State University (described in the next section), were used to develop a detailed and robust university submodel system. The proposed framework includes:

- Separate model components by student level (graduate student, undergraduate student) and living arrangement (on-campus, off-campus) to recognize the differing travel patterns exhibited by various market segments (Eom et al., 2009; Khattak et al., 2011; Wang et al., 2012)
- Separate model components for faculty/staff travel and student travel to reflect the unique travel patterns of students (Akar et al., 2012)
- A parking infrastructure measure to reflect the impact of parking pricing and availability on mode shares (Alshuwaikat and Abubakar, 2008; Barata et al., 2011; Shang et al., 2007; Prolux et al., 2014)
- Separate treatment of intra- and non-intra campus travel as these distinct trip types exhibit very different characteristics and underlying motivating influences.

The model design deviates slightly from the traditional four-stage modeling paradigm to incorporate features that are unique to a university context. Universities have data on student enrollment and faculty/staff numbers at the university level. Due to the large swaths of land covered by university campuses, a large university is often designated by multiple traffic analysis zones. However, it is difficult to apportion the faculty/staff numbers and student enrollment to the distinct zones due to a lack of data. Such apportionment could be done based on a weighted measure of the share of each zone to the area of the university, share of building square footage in each zone to total built-up area on the campus, and other such allocation processes; however, such processes are – at best – approximate and could lead to potential misallocation of university population segments to various zones.

For this reason, the framework in this study treats all university zones as comprising a single university super-zone for purposes of modeling non-intra-university travel. The university super-zone is disaggregated into separate university zones in specific steps of the destination and mode choice models. The output of the mode choice component of the university submodel can be easily combined with modal trip matrices from the main regional travel model to generate overall origin-destination (OD) matrices for network assignment. The overall framework is shown in Fig. 1. The approach presented here is generic to any market segment (for example, graduate students), trip purpose (for example, home-based university), and time of day (for example, peak). For illustrative purposes, a hypothetical university with four zones is shown, but the framework is flexible enough to accommodate any zonal configuration.

First, trips attracted by the super university zone are derived by multiplying the trip rate pertaining to a market (and trip) segment by the enrollment/employment corresponding to that segment (Fig. 1, Panel A). The attraction end of all campus-based trips is fixed as the university super-zone. The destination choice model embedded in the framework is aimed at determining the production end of the university-based trips, which is a deviation from the classic four-step travel demand modeling paradigm where productions are known and attraction end is modeled through the destination choice step.

Thus, the destination choice model in the university submodel may be viewed as a location choice model to identify the production ends of the university-based trips. There are two major trip purposes considered in the context of the framework, namely, home-based university (HBU) trips – in which the home end is modeled, and non-home-based university (NHBU) trips in which the non-home-end is modeled. The identification of production ends using the location choice models results in production-attraction matrices (PA matrices) that provide a measure of the spatial configuration of trip exchanges in the region that involve the university as one trip end (Fig. 1, Panel B).

Next, the mode choice model is applied. The mode choice model splits the matrices output by the location choice models into separate mode-specific matrices (Fig. 1, Panel C). Only three modal matrices are shown in the figure for illustrative purposes, but the framework can accommodate any number of modes. In the figure, cell Y of the matrix corresponds to intra-campus (IC) trips while the cells marked with the letter X correspond to non-intra-campus (NIC) trips.

2.1. Incorporating sensitivity to parking infrastructure and campus shuttle services

Parking sensitivity is incorporated in the mode choice models by introducing a university parking attraction factor (UPAF) in the auto utility equations of the nested logit mode choice model. The UPAF is a function of parking capacity and generalized parking cost on campus:

$$UPAF \alpha f\left(\frac{\text{Parking Capacity per Capita}}{\text{Generalize cost of parking on Campus}}\right) \tag{1}$$

The parking capacity per capita is the number of parking spaces available per individual in the university population (faculty+staff+students). With an increase in parking capacity per capita, the campus becomes more attractive for using personal vehicle modes. The generalized parking cost accounts for the cost of parking in various parking facilities (lots and garages), the distance of various parking facilities from the central core of the campus, and the parking capacity of various facilities. In other words, the generalized parking cost is a parking capacity weighted composite measure of parking convenience and price. The formulation is as follows (where *i* refers to a specific parking lot, and *n* is the total number of parking facilities):

$$\text{Generalized Parking Cost} = \frac{\sum_{i=1}^{n} \text{avg\_cost}_i \times \text{distance}_i \times \text{capacity}_i}{\text{Total Parking Capacity on Campus}} \tag{2}$$

Another feature incorporated in the framework is the inclusion of campus shuttle services as a specific mode of travel. Many university campuses operate shuttle services to connect remote parking facilities with the academic core of the campus, connect multiple campus locations, and help students get around campus. The campus shuttle mode may be included as a separate mode in the mode choice model, treating it as a regular walk-accessed local bus service with no fare.

2.2. Distinct treatment of intra- and non-intra-campus travel

After the mode choice step (where the university is treated as a single super-zone), the non-intra-campus and intra-campus trips need to be treated separately due to their unique characteristics. The process utilized to spatially allocate these respective trips across the multiple traffic analysis zones that comprise the university is shown in Fig. 2. For non-intra-campus trips, each modal matrix is expanded to accommodate the specific university zones (four in this illustration). The attractions of the university super-zone are apportioned to each of the university zones based on an intensity measure that captures classroom and parking intensity in a manner that is specific to each mode (Fig. 2, Panel A). For example, a higher number of single occupant vehicle (SOV) trips would presumably be attracted by a university zone that has substantial parking infrastructure. A parking intensity measure (or attractiveness measure) can be computed for each zone given parking inventory information for the university.

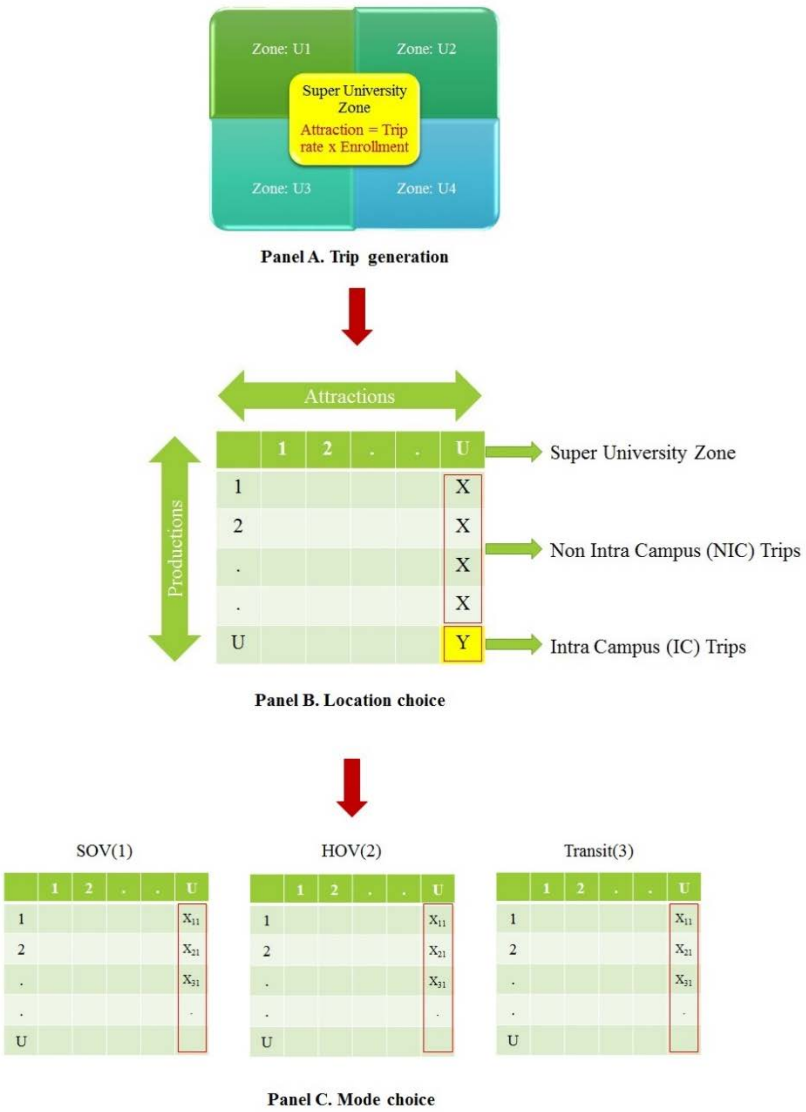

Fig. 1. University travel demand modeling framework.

Single occupant vehicle trips are then apportioned in accordance with the relative parking intensity of various university zones. Similarly, transit and walk/bike trips attracted by the campus are likely to be associated to a greater degree with zones that house academic activities such as classroom buildings, administrative functions, and the library (as opposed to zones that are largely parking intensive). Non-intra-campus trips by these modes are allocated in accordance with the relative intensity of academic and administrative function. The framework is flexible in that intensity measures used to allocate trips by various modes across the multiple zones that comprise a university can be customized to a specific university context.

Intra-campus trips are treated somewhat differently. A gravity model-inspired spatial allocation process is introduced to apportion IC trips across university zones. An intra-campus attraction weight measure that can be used for spatial allocation purposes is computed as follows:

$$Proportion\left(P_{ij}\right) = \left(\frac{A_i A_j}{A^2}\right) \qquad (3)$$

where,
P_{ij} – Weight measure for zone pair 'i, j'
A_i – Total non-intra-campus attractions for zone 'i'
A_j – Total non-intra-campus attractions for zone 'j'
A – Total non-intra-campus attractions

The trip flow between a zone pair is determined based on the attractiveness of each of the zones. In this framework, the attractiveness measures are based on the non-intra-campus trip apportionment (intensity). The logic behind the use of this spatial allocation measure is that two zones that attract large numbers of non-intra-campus trips will likely exchange a higher proportion of intra-campus trips. For example, consider a zone that has very high parking intensity. Many non-intra-campus trips (by auto) would be attracted by this zone. Similarly, consider another zone that has a high classroom intensity that would also attract many non-intra-campus trips. Both of these zones will exchange a large share of trips (for example, individuals walking between parking facilities and classroom buildings). In order to prevent trip exchanges that are very small or virtually non-existent, certain modal exchanges are disallowed. For example, consider two zones that are heavily parking-intensive. Although the proportion factor computed using equation (3) would be large for such a zone pair, trip exchanges between these two zones are disallowed because it is unlikely that individuals would travel between two parking zones. Thus the proportion computations are done only for zone pairs that would see a substantial exchange of intra-campus trips (parking – classroom, classroom – classroom). Several zones may have mixed land use (combination of parking and classroom space), and trip exchanges by various modes are generally allowed for such mixed zones.

Finally, the intra-campus and non-intra-campus modal matrices are combined (Fig. 2, Panel C) into one single matrix. The modal matrices from the university submodel are integrated with their counterparts in the main regional travel model prior to traffic assignment.

3. Data from Arizona State University travel survey

Prior to presenting the Albuquerque metro area application of the university submodel framework, a brief overview of the data used for the case study is provided in this section. The University of New Mexico and the Central New Mexico Community College are key institutions of higher education in the Albuquerque metropolitan area that influence travel demand in the region. However, there is no detailed disaggregate travel diary survey of the university population for these institutions. Hence an alternative data source had to be used in order to develop the university submodel for the Albuquerque metropolitan area. The alternative data source used for the application is the extensive travel survey data set collected on the campus of Arizona State University during the Spring of 2012. Arizona State University is a large public university in the southwest United States, located in a sprawled metropolitan region. Albuquerque is smaller in scale than the Greater Phoenix metropolitan region, but exhibits similar sprawled land use patterns and very low transit mode shares. Moreover, Albuquerque is also located in the southwest United States, and the University of New Mexico and Central New Mexico Community College together influence regional travel demand in a manner consistent with the way in which Arizona State University travel affects regional travel demand in the Greater Phoenix metropolitan region. Both campuses offer some on-campus housing, have many students living at the edge of campus, and operate shuttle services for students to get around campus and access remote parking facilities.

The Arizona State University travel survey was administered completely online over a three week period in the spring semester of 2012. Information collected in the survey includes socio-demographic information, information from a complete one-day travel diary in which respondents were asked to report all trips (including non-university based trips) for a 24 hour period of the most recent weekday, information on typical or usual travel to and from the university and to and from work, and attitudes and perceptions towards various modes of transportation.

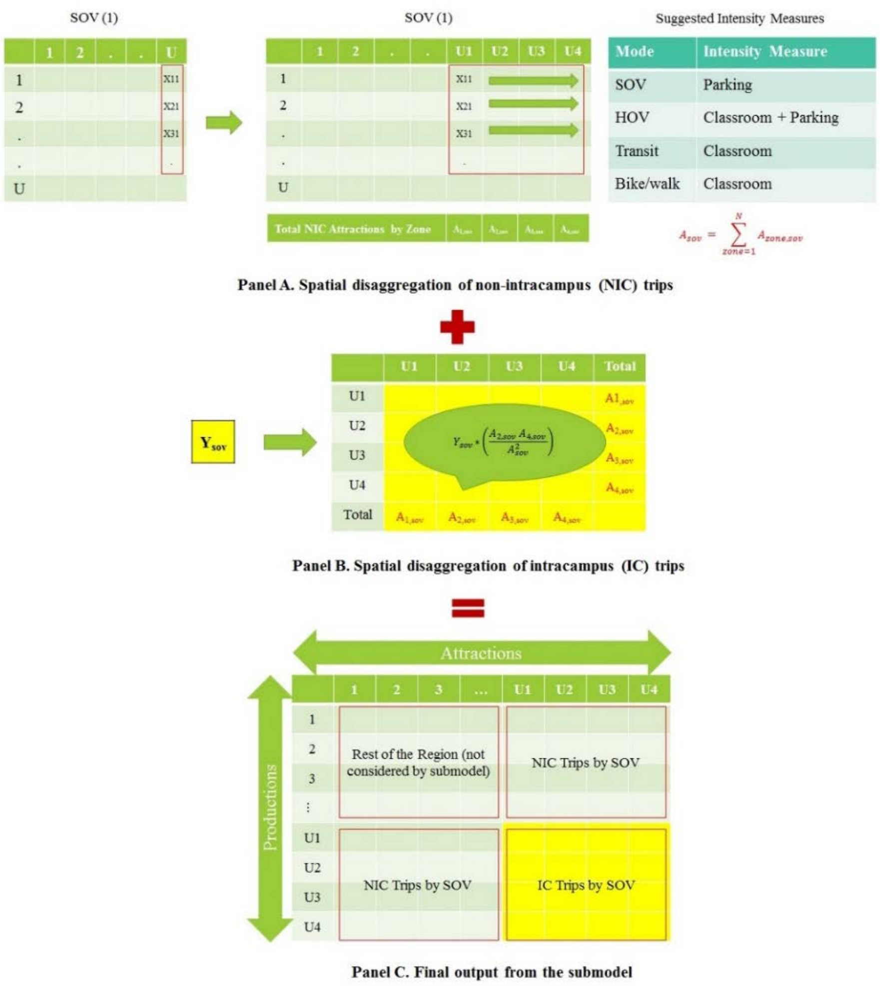

Fig. 2. Framework for treatment of intra- and non-intra-campus travel.

The survey was widely publicized in an effort to maximize the response rate. A detailed description of the survey and the characteristics of the respondent sample may be found elsewhere (Volosin et al., 2014). More than 12,000 responses were obtained, about 10,000 of whom were students, 1,500 of whom were staff, and 500 of whom were faculty. Weights were developed in order to ensure that weighted statistics represented the characteristics of the overall university population. The characteristics of the university population were found to be quite similar with patterns reported in the literature, which suggested that it may be appropriate to apply information from the Arizona State University survey for the Albuquerque metropolitan area university submodel development effort. As expected, faculty and staff exhibited more classical time of day distributions of travel with peaks in the morning and evening, while students showed a time of day distribution of travel that was heavily based on mid-day travel with small spikes associated with class start and end times. Also, a majority of university-based trips made by students were intra-campus trips, and a large proportion of the intra-campus trips were made by non-motorized modes. This data served as the basis for the development of the University of New Mexico (UNM) and Central New Mexico (CNM) community college submodel for the Albuquerque metropolitan area. The models were calibrated and adjusted to match some aggregate data that was available locally in the region (related to typical university population parking and travel characteristics).

4. Case study application for Albuquerque metropolitan area

The university submodel framework described previously was implemented as part of the comprehensive travel demand model update for the Mid-Regional Council of Governments (MRCOG) in the Albuquerque metropolitan area. The region has a total of about 3.4 million trips each day across 919 traffic analysis zones. The UNM and CNM campuses encompass an area covered by 20 traffic analysis zones and contribute to about 180,000 trips in the region each weekday. Both of the institutions of higher education are adjacent to one another, thus presenting one contiguous area that could be treated as a super-zone consistent with the framework described in this paper. The institutions together have an enrollment of 42,000 students and employ about 18,000 faculty and staff. Small sample surveys of the university population had been conducted in the past few years. A comparison of aggregate travel characteristics between the Arizona State University survey sample and the small Albuquerque-based survey samples suggested that, in the aggregate, travel characteristics are quite similar. Because the Albuquerque-based survey samples were small and did not include a detailed travel diary component, the data from the Arizona State University survey was used to estimate models – and the aggregate travel patterns in the Albuquerque small sample data sets were used to calibrate the models to the local region. It cannot be emphasized enough that great care and professional judgement must be exercised when using data collected in one area to develop models for another area.

Multiple rounds of review and extensive consultations were held to ensure that the travel patterns predicted by the resulting university submodel were consistent with local knowledge of actual travel patterns in the region, and especially in and around the institutions of higher education. An extensive market segmentation scheme was adopted for the university submodel specification, primarily to recognize differences in travel characteristics across the subpopulations, trip purposes, and time of day. The market segmentation scheme is shown in Fig. 3.

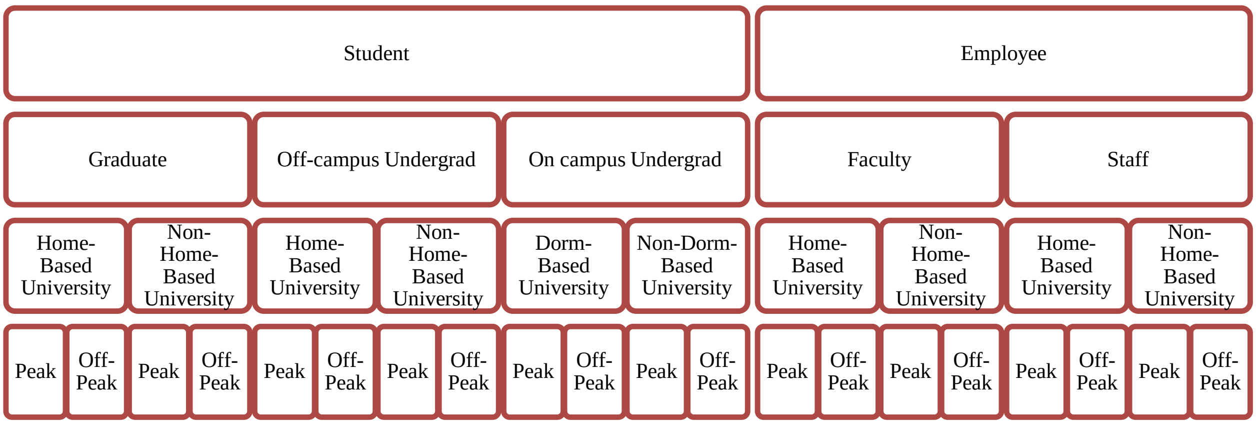

Fig. 3. Market segmentation considered for UNM/CNM submodel.

This segmentation is based on a thorough analysis of the survey data to identify distinct segments with varying travel patterns as well as findings from pertinent studies on university population travel characteristics. Home-based university and non-home-based university trip purposes are aggregated after the location choice modeling step to simplify the mode choice model specification; the mode choice component of the university submodel therefore has one model per market segment per time period (peak, off peak). Case study results are briefly presented in this section.

4.1. Trip generation

Trip attraction rates are computed using weighted survey data from Arizona State University for different market segments and then adjusted slightly to match the data available in the Albuquerque metropolitan area. Trip rates for all market segments are shown in Table 1. These rates are used in conjunction with enrollment and employment numbers to derive trip attractions to the university, classified by market segment, purpose, and time-of-day. From the table, it can be observed that on-campus undergraduate students had greater trip rates than off-campus undergraduate students and graduate students. This observation is consistent with findings reported in the literature (Eom et al., 2009; Khattak et al., 2011). It can also be seen that faculty and staff trip rates are noticeably different from that of student segments. In fact, the faculty and staff home-based university and non-home-based university trip rates were quite similar to the home-based work and non-home-based work trip rates (for workers) in the MRCOG regional household travel survey. This similarity is consistent with expectations, suggesting that faculty and staff travel may be modeled using data for workers available in a general purpose household travel survey.

Table 1. Trip rates by market segment.

Segment	Home-Based University		Non-Home-Based University	
	Peak	Off-Peak	Peak	Off-Peak
Graduate	0.62	0.74	0.71	0.82
Off-Campus Undergraduate	0.48	0.56	0.54	0.86
On-Campus Undergraduate (Dorm Based)	0.93	1.42	0.99	1.66
Faculty	0.99	0.94	0.77	1.12
Staff	1.05	0.90	0.80	1.06

4.2. Location Choice

Trip attractions computed for each purpose serve as input to the location choice models. Location choice models are calibrated with a view to identify the production (non-university) end of university-based travel. The only exception to this rule is the case of on-campus undergraduate students who reside in dorms. As they live on campus, the university end of their trips is always the production if the university trip end is located in the dorms. For this one trip type, the location choice models are employed to identify the attraction end of the trips (which may include the university super-zone as well; for example, a student walking between his or her dorm and a classroom building to attend class). In the interest of brevity, model estimation results are not furnished in this paper. The location choice model is a multinomial logit model with a logsum term (from the mode choice model), a host of land use size descriptors, and a few distance-based dummy variables introduced with a view to replicate observed trip length distributions in the survey data set. In general, the location choice models offered acceptable goodness of fit; for example, the location choice model for non-home-based university trips for off-campus undergraduate students was found to offer a rho-square-adjusted value of 0.673, which is considered quite high for a disaggregate choice model of this nature.

Models offered behaviorally intuitive and consistent indications. For example, the same model of non-home-based university trips for off-campus undergraduate students indicated that zones with high retail employment are more likely to serve as the non-university trip end for these types of trips. Students may be traveling to and from these zones for shopping, personal business, social relaxation, and work/work-related activities. Zones that have high population density are more likely to serve as ends for non-home-based university trips. Zones with a high proportion of single family homes are less likely to produce non-home-based university trips; these are zones that are more likely to produce home-based university trips.

Trip length distribution patterns predicted by the model are compared with those observed in the Arizona State University travel survey to check and calibrate the model. Model calibration results for non-home-based trips made by off-campus undergraduate students in the peak period are shown in Fig. 4. It can be seen from the figure that the model replicates observed trip length distributions quite well. In addition, the model is able to accurately replicate the share of intra-campus trips for this trip purpose. Separate treatment of intra- and non-intra-campus trips was generally found to yield substantial benefits in model performance and fit.

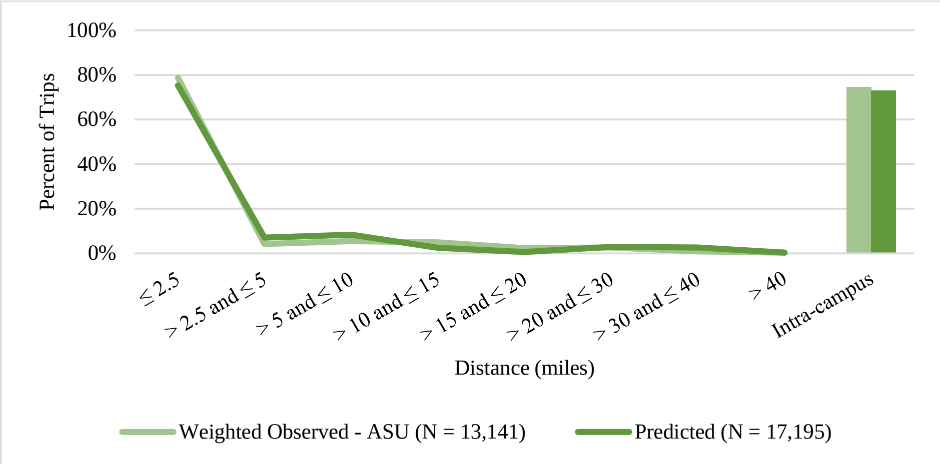

Fig. 4. Location choice model validation for non-home-based university trips: off-campus undergraduates (peak period).

4.3. Mode choice

The mode choice model structure of the main regional travel demand model was adapted for use in the university submodel. The nested logit model structure consists of auto, non-motorized, and transit branches, with submodes under each branch to reflect single versus multi-occupant car travel, walk versus bicycle, and premium versus local transit. An additional campus shuttle mode operated by the Parking and Transit Services (PATS) of the university was added to the transit nest as a walk to local mode with zero fare. The PATS shuttle is operated by the UNM/CNM campus administration so that members of the university community can access remote parking lots located in the north and south parts of the campus. Mode choice model coefficients were not estimated, but largely asserted based on parameters in the existing main regional travel model mode choice specification and other guidance offered by the Federal Transit Administration. Bias constants in each of the utility equations are adjusted to match target values as closely as possible.

After the mode choice step, the effectiveness of the framework was tested. Checks were made to see whether the submodel framework could match the target mode share values across different market segments, trip purposes, and times of the day. Comparison between observed and predicted mode shares is shown in Table 2. Based on the comparisons (target versus model), it can be seen that the model matches the target values exceptionally well across all market segments. Further the differences in mode share patterns across market segments are clearly evident. In the student groups, graduate as well as off-campus undergraduate students exhibit similar modal shares with an even split between non-motorized and auto modes. Mode shares of these two segments are completely different from those of on-campus undergraduate students who make a majority of their trips by walk and bicycle. Employees of the university have an auto-dominated mode share pattern, and the model is able to effectively capture these differences across market segments. Overall, the submodel framework was found to work quite effectively in representing the unique trip making patterns corresponding to the UNM/CNM campus.

Table 2. Mode choice model validation results.

A. Student-Segment				
Mode	**Graduate**		**Off-Campus Undergraduate**	
	Target	**Model**	**Target**	**Model**
Walk	32.00%	30.80%	40.10%	38.50%
Bike	10.60%	10.30%	7.50%	7.30%
Drive Alone	37.50%	39.10%	31.40%	33.20%
Shared Ride 2	6.90%	7.10%	6.00%	6.30%
Shared Ride 3+	3.00%	3.10%	3.80%	3.90%
Walk to Local	1.00%	1.00%	0.90%	1.00%
Walk to Premium	0.40%	0.30%	0.30%	0.30%
PATS Shuttle	7.20%	6.90%	8.60%	8.20%
PNR Local	0.60%	0.60%	0.60%	0.60%
PNR Premium	0.30%	0.30%	0.30%	0.30%
KNR Local	0.40%	0.40%	0.40%	0.40%
KNR Premium	0.10%	0.10%	0.10%	0.10%
Total Trips	21561	21561	77650	77650
B. Living Arrangement				
Mode	**On-campus Undergraduate (Dorm-Based)**		**On-campus Undergraduate (Non-Dorm-Based)**	
	Target	**Model**	**Target**	**Model**
Walk	46.20%	45.10%	46.20%	46.00%
Bike	10.20%	10.00%	10.60%	10.50%
Drive Alone	16.50%	17.70%	16.80%	16.90%
Shared Ride 2	12.10%	12.20%	12.90%	13.00%
Shared Ride 3+	7.70%	7.80%	7.20%	7.20%
Walk to Local	1.40%	1.50%	1.70%	1.90%
Walk to Premium	0.50%	0.40%	0.40%	0.30%
PATS Shuttle	4.90%	4.70%	3.60%	3.60%
PNR Local	0.00%	0.00%	0.00%	0.00%
PNR Premium	0.00%	0.00%	0.00%	0.00%
KNR Local	0.40%	0.40%	0.40%	0.40%
KNR Premium	0.10%	0.10%	0.10%	0.10%
Total Trips	6607	6607	7467	7467
C. Administrative Appointment				
Mode	**Faculty**		**Staff**	
	Target	**Model**	**Target**	**Model**
Walk	14.30%	14.50%	8.80%	9.40%
Bike	11.40%	11.60%	15.20%	15.60%
Drive Alone	62.40%	61.90%	63.20%	62.00%
Shared Ride 2	5.80%	5.80%	6.80%	6.90%
Shared Ride 3+	1.30%	1.30%	0.90%	0.90%
Walk to Local	0.80%	1.20%	0.90%	1.20%
Walk to Premium	0.20%	0.30%	0.20%	0.30%
PATS Shuttle	2.10%	2.00%	2.10%	2.00%
PNR Local	1.20%	1.10%	1.30%	1.20%
PNR Premium	0.30%	0.30%	0.30%	0.30%
KNR Local	0.20%	0.20%	0.20%	0.20%
KNR Premium	0.00%	0.10%	0.10%	0.10%
Total Trips	17143	17143	50572	50572

PNR - Park and Ride
KNR - Kiss and Ride
PATS - Parking and Transit Services

5. Assessment of Model Efficacy

After the successful validation of the model framework, an additional assessment was undertaken to test the features of the framework that are unique to a university setting. Results of the analyses are presented in this section.

5.1. Sensitivity to parking infrastructure configuration

An assessment of model efficacy was performed by testing the impact of parking attractiveness factor on mode share. The model was run for the base case (existing parking infrastructure on university campuses) and then run again for a scenario where the parking attractiveness factor was reduced by a factor of 40 percent. Results of the scenario analysis (shown in Table 3) demonstrated that the model is sensitive to the parking attractiveness factor in behaviorally intuitive ways, consistent with elasticity measures as reported in TCRP Report 95, Chapter 13 (Vaca and Kuzmyak, 2005) and Chapter 18 (Kuzmyak et al., 2003).

Table 3. Effect of university parking attraction factor (UPAF) on mode share.

UPAF = 0.18 → Base				
Segment	**Non-motorized**	**Auto**	**Transit**	**PATS-Shuttle**
Graduate Students	4946	5560	300	860
Off-Campus Undergraduate	22976	17306	1103	3779
On-Campus Undergrad (Dorm-Based)	2221	1460	98	204
On-Campus Undergrad (Non-Dorm-Based)	2661	1717	121	174
Faculty	2481	6287	300	198
Staff	6581	17944	919	550
Total	41865	50275	2840	5766
UPAF = 0.11 (40% ↓) → Decrease in Parking Attractiveness				
Graduate Students	5315	5244	380	726
Off-Campus Undergraduate	24156	16339	1305	3362
On-Campus Undergrad (Dorm-Based)	2274	1410	104	196
On-Campus Undergrad (Non-Dorm-Based)	2757	1619	129	168
Faculty	2730	6004	372	160
Staff	7165	17272	1120	437
Total	44398	47888	3411	5049
Difference (Decrease - Base)				
Graduate Students	369	-316	80	-134
Off-Campus Undergraduate	1180	-967	202	-417
On-Campus Undergrad (Dorm-Based)	53	-50	6	-8
On-Campus Undergrad (Non-Dorm-Based)	96	-98	8	-6
Faculty	249	-283	72	-38
Staff	584	-672	201	-113
Total	2533	-2387	571	-717

Note: PATS Shuttle is the Parking and Transit Services Shuttle that connects remote parking facilities with the center of campus.

A decrease in parking attraction is associated with a decrease in auto trips and increase in non-motorized and transit shares, as expected. What is especially meaningful is that the number and share of PATS shuttle trips also registered a drop. This is consistent with expectations because PATS shuttle is largely used to access remote parking lots; if the number of auto trips decreases in the alternate parking scenario, then the number of PATS shuttle trips should show a corresponding decrease as well.

5.2. Representation of intra-campus trips by mode

An assessment was done to analyze flow patterns between different parts of the UNM/CNM campus. The campus zones were aggregated into north, central, and south sectors, with all non-university zones in the region treated as "other" (see Fig. 5).

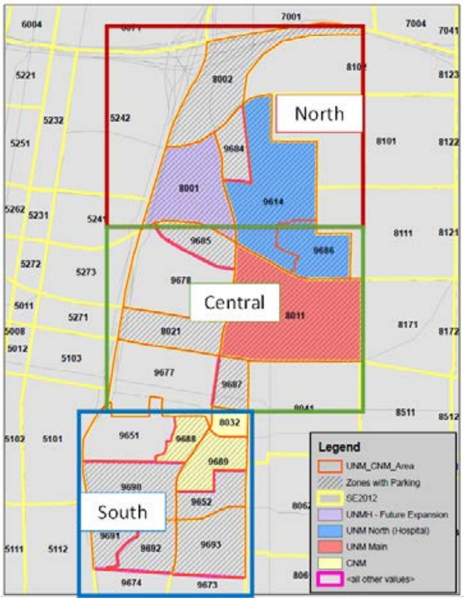

Fig. 5. Map depicting campus sectors for sensitivity analysis.

Travel flow matrices by mode were computed to assess whether the university submodel was able to predict reasonable patterns of travel by mode both within the university and between the university and the rest of the region. Table 4 presents the summary results of the campus flows by mode. In general, it was found that the model replicated spatial and modal flow patterns very well.

Table 4. Daily Flows by Mode Predicted by University Submodel.

	North	**Central**	**South**	**Other**	**Total**	**North**	**Central**	**South**	**Other**	**Total**
	Auto					**Non-Motorized**				
North	0.40%	0.80%	0.70%	0.40%	**2.30%**	4.00%	9.00%	6.00%	0.00%	**19.00%**
Central	0.80%	1.50%	1.20%	0.60%	**4.00%**	9.00%	20.00%	13.40%	0.00%	**42.30%**
South	0.70%	1.20%	1.00%	0.60%	**3.50%**	6.00%	13.40%	8.90%	0.00%	**28.30%**
Other	23.00%	29.90%	37.40%	0.00%	**90.30%**	2.20%	4.90%	3.30%	0.00%	**10.30%**
Total	**24.90%**	**33.30%**	**40.20%**	**1.60%**	**N = 93931**	**21.20%**	**47.20%**	**31.50%**	**0.10%**	**N = 71429**
	Transit					**Other (PATS Shuttle)**				
North	0.10%	0.20%	0.10%	0.60%	**1.00%**	4.50%	10.00%	6.70%	0.00%	**21.10%**
Central	0.20%	0.50%	0.30%	1.30%	**2.30%**	10.00%	22.20%	14.80%	0.00%	**47.00%**
South	0.10%	0.30%	0.20%	0.90%	**1.60%**	6.70%	14.80%	9.90%	0.00%	**31.40%**
Other	20.20%	44.90%	30.00%	0.00%	**95.10%**	0.10%	0.20%	0.10%	0.00%	**0.40%**
Total	**20.60%**	**45.90%**	**30.70%**	**2.80%**	**N = 5330**	**21.20%**	**47.20%**	**31.60%**	**0.00%**	**N = 10305**

Note: Shaded cells correspond to intra-campus flows.

The Other ↔ North/Central/South cells of the matrices correspond to non-intra-campus flows while the rest of the cells (shaded grey) correspond to intra-campus flows by mode. It was found that auto and transit modes, which are usually utilized to travel to/from the campus, load heavily in the non-intra-campus flow cells. On the other hand, PATS shuttle and non-motorized modes which would be largely associated with short intra-campus trips are found to load heavily in the intra-campus flow cells. The model predicted that 99.6 percent of PATS trips are intra-campus; this indicates that the model is returning predictions consistent with real-world observations (because the PATS shuttle is generally exclusively used for intra-campus travel).

6. Conclusions

Large universities contribute substantially to travel demand in a region. Travel behavior of university populations (especially students) is quite different from that of the general population due to the unique nature of university operations, class schedules, and calendars. There has been an increasing interest over the past decade to study university student travel patterns and several student travel surveys have been conducted at universities around the world. Data from the surveys reveal that student travel patterns are indeed different from those of the general population, and that even within the student population, travel patterns differ by level of student (graduate versus undergraduate) and living arrangement (on-campus versus off-campus).

Although university population travel behavior data is beginning to become available, there is a lack of operational modeling frameworks to accurately forecast university-specific travel demand. To fill this gap, the current study proposes a comprehensive framework aimed at modeling university-based travel for faculty, staff and students. The university submodel framework generally follows the four-step travel modeling paradigm, but includes several key features to accommodate university-specific contexts and policy applications. A couple of key features of the submodel include: i) accounting separately for intra-campus and non-intra-campus travel, as they may have drastically different trip lengths and mode shares; and ii) incorporation of university parking attractiveness as an explanatory factor into the mode choice component of the university submodel. Other features of the submodel include the addition of a university campus shuttle service as an additional mode in the mode choice model, extensive market segment by student and employee class, trip purpose, and time of day, and the use of a location choice model to identify trip production locations (because the university is treated as the attraction end). The submodel first treats all university zones as a single super-zone to model non-intra-campus travel demand, and then implements a spatial allocation procedure to locate non-intra-campus trip ends within different university zones and estimate intra-campus travel between specific university zones.

A case study in which the submodel is applied in the context of two large universities (University of New Mexico and Central New Mexico Community College) in Albuquerque, New Mexico is presented. In light of limited data availability for model development, travel survey data collected at Arizona State University in the Greater Phoenix metropolitan region was utilized to model university travel in the Albuquerque metropolitan area. Results from the case study show that the framework performs very well in representing and replicating the travel patterns of the university population. Exercises were carried out to test i) the model's sensitivity to parking configuration on the university campuses, and ii) the model's ability to accurately represent the intra and non-intra-campus flow patterns by mode. Results from the sensitivity analysis exercises corroborate the model's ability to capture university travel patterns in behaviorally intuitive ways.

An operational prototype of the framework has been coded and implemented in an open source coding platform based on the Python programming language to facilitate seamless integration into any regional travel demand modeling software. Extensive scenario and sensitivity analyses are being carried out on the Albuquerque implementation of the submodel to test the robustness and policy sensitivity of the framework. Extensions to the submodel could include further disaggregation of student segments by employment categories (off-campus versus on-campus employment) and validation of model outputs against secondary data sources.

References

Akar, G., Flynn, C., Namgung, M., 2012. Travel Choices and Links to Transportation Demand Management: Case Study at Ohio State University. In Transportation Research Record: Journal of the Transportation Research Board 2319, 77-85.

Alshuwaikhat, H. M., Abubakar, I., 2008. An Integrated Approach to Achieving Campus Sustainability: Assessment of the Current Campus Environmental Management Practices. Journal of Cleaner Production 16 (16), 1777-1785.

Balsas, C. J., 2003. Sustainable Transportation Planning on College Campuses. Transport Policy 10 (1), 35-49.

Barata, E., Cruz, L., Ferreira, J. P., 2011. Parking at the UC campus: Problems and Solutions. Cities 28 (5), 406-413.

Behrens, R., Freedman, M., McGuckin, N., 2008. The Challenge of Surveying 'Hard to Reach' Groups. Presented at 8th International Conference on Survey Methods in Transport: Harmonization and Data Quality, Annecy, France.

Eom, J. K., Stone, J. R., Ghosh, S. K., 2009. Daily Activity Patterns of University Students. Journal of Urban Planning and Development 135, 141-149.

Khattak, A., Wang, X., Son, S., Agnello, P., 2011. Travel by University Students in Virginia: Is this Travel Different from Travel by the General Population? In Transportation Research Record: Journal of the Transportation Research Board 2255, 137-145.

Kuzmyak, J. R., Weinberger, R., Pratt, R. H., Levinson, H. S., 2003. Parking Management and Supply, Chapter 18, TCRP Report 95, Transit Cooperative Research Program, Transportation Research Board, Federal Transit Administration. Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c18.pdf, Accessed 25 September, 2015.

Namgung, M., Akar, G., 2015. Influences of Neighborhood Characteristics and Personal Attitudes on University Commuters' Public Transit Use. Presented at 84th Annual Meeting of the Transportation Research Board, Washington, D.C.

Poinsatte, F., Toor, W., 1999. Finding a New Way: Campus Transportation for the 21st Century. University of Colorado: Boulder.

Popovich, N., 2014. Results of the 2013-14 Campus Travel Survey. Research Report – UCD-ITS-RR-14-14. Available at: http://www.its.ucdavis.edu/research/publications/publication-detail/?pub_id =2347, Accessed 26 September, 2015.

Proulx, F. R., Cavagnolo, B., and Torres-Montoya, M., 2014. The Impact of Parking Pricing and Transit Fares on Mode Choice to a Major University Campus. Presented at 93rd Annual Meeting of the Transportation Research Board, Washington, D.C.

Rodríguez, D. A., Joo, J., 2004. The Relationship between Non-Motorized Mode Choice and the Local Physical Environment. Transportation Research Part D: Transport and Environment 9 (2), 151-173.

Shang, H., Wenji, L. I. N., Huang, H., 2007. Empirical Study of Parking Problem on University Campus. Journal of Transportation Systems Engineering and Information Technology 7 (2), 135-140.

Shannon, T., Giles-Corti, B., Pikora, T., Bulsara, M., Shilton, T., Bull, F., 2006. Active Commuting in a University Setting: Assessing Commuting Habits and Potential for Modal Change. Transport Policy 13 (3), 240-253.

Tolley, R., 1996. Green Campuses: Cutting the Environmental Cost of Commuting. Journal of Transport Geography 4 (3), 213-217.

Vaca, E., Kuzmyak. J. R., 2005. Parking Pricing and Fees, Chapter 13, TCRP Report 95, Transit Cooperative Research Program, Transportation Research Board, Federal Transit Administration,. Available at: http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c13.pdf, Accessed 25 September, 2015.

Volosin, S. E., Pendyala, R. M., Kerrigan, J., Greene, E., Livshits, V., and Samuelson, J., 2014. Measuring the Travel Characteristics of a University Population: Experiences from the Design and Administration of a Web-based Travel Survey. Presented at 93rd Annual Meeting of the Transportation Research Board, Washington, D.C.

Wang, X., Khattak, A., Son. S., 2012. What Can be Learned from Analyzing University Student Travel Demand?. In Transportation Research Record: Journal of the Transportation Research Board 2322, 129-137.