A case study of induced trips at mixed-use developments

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Abstract. Conventional thinking suggests that pedestrian-friendly, mixed-land-use developments will contribute to an overall reduction in travel by providing an alternative to automobile travel. However, these elements may serve to increase travel demand by reducing the overall cost of travel—a phenomenon generally known as ‘induced’ travel. To date, most studies of induced travel have focused on aggregate travel patterns, without examining how development patterns may influence people’s trip-making decisions. To fill a void in the empirical research, we examine the potential for induced trip making at mixed-use developments by analyzing data obtained from a survey of travelers at a typical mixed-use site in suburban Dallas, Texas, USA. Our analysis found that during both the morning and afternoon study periods, at least some percentage of internal trips at the case-study site were induced, and not ‘captured’ from the external street network as is typically assumed. Induced trips by land-use pair and travel mode are also reported. Even with the induced trips, a reduction in regional vehicle-miles traveled can still be realized at mixed-use developments sites due to the propensity for those trips to be made on foot. Induced travel also has implications for the development of traffic-impact studies for proposed mixed-use sites, which generally assume that all internal trips are replacing external trips. Planners, policy makers, politicians, and other stakeholders exploring mixed-use developments are encouraged to consider the implications of induced travel in the mixed-use environment as a land-use solution to urban traffic congestion and air-quality issues.

Keywords: induced trips, mixed-use developments, neotraditional neighborhood development, traffic impact analysis, trip generation

1 Introduction

In the last quarter century, research has emerged resulting in an improved understanding of the impacts of land development on travel behavior (see, for example, reviews by Ewing and Cervero, 2001; 2010). Consequently, there is an increased level of awareness of the connection between the nature of the built environment and traffic congestion, air quality, and livability. In response, the planning, policy, and real-estate development communities have embraced the construction of compact, pedestrian-oriented, mixed-land-use developments as an alternative to the sprawling, low-density, single-use projects that dominated development patterns in the United States after World War II. Branded with names like neotraditional neighborhood development, New Urbanist town center, transit-oriented development, or pedestrian pocket, some physical characteristics of such developments include (Berman, 1996):

- a mixed-use core within walking distance of residents;
- employment and civic centers;
- streets in a grid pattern that provide multiple paths for drivers and pedestrians;
pedestrian-oriented streets with wider sidewalks that are protected from vehicle traffic via on-street parking, traffic calming, or shade trees acting as a buffer;

- narrow streets with sidewalks and alleys running behind homes;
- housing for different income levels;
- higher housing density and smaller lots than those in conventional suburbs;
- streets that are social spaces as well as transportation facilities; and
- common open spaces such as village greens.

Conventional wisdom suggests that the traveler’s ability to accomplish multiple trip purposes at a single destination and the pedestrian-friendly design of these developments, if properly implemented, can provide urban areas with much-needed transportation-related benefits. For the most part, existing research on the topic of travel behavior at mixed-use developments has supported this, demonstrating that mixed-use developments have the potential to capture some trips within the site that would otherwise have utilized the public street system (Ewing et al, 2001; Institute of Transportation Engineers, 2004; Khattak and Rodriguez, 2005) and that a higher percentage of trips within these developments are made on foot (Cervero and Radisch, 1996; Frank and Pivo, 1994; Freidman et al, 1994; Khattak and Rodriguez, 2005; McCormack et al, 2001; Moudon et al, 1997). At a regional level, mixing land uses has been shown to contribute to a reduction in various measures of vehicle travel (Ewing et al, 1994; Gordon and Peers, 1994; McCormack et al, 2001; Walters et al, 2000). For politicians, policy makers, local stakeholders, and the broader planning community, the site-level and regional-level travel benefits of mixed-use developments (that is, anticipated reductions in vehicle travel on the public road system) are difficult to ignore, particularly in urban areas where traffic congestion imposes travel-cost, environmental, and quality-of-life burdens on residents and travelers alike.

Elements of the mixed-use environment which are purported to reduce travel, such as the interactive land-use mix, the pedestrian-oriented atmosphere, or the compactness of the development may increase the overall demand for travel since they often reduce the costs of travel. This increase in overall demand for travel, known as ‘induced’ travel, has serious implications for the magnitude of transportation benefits expected to be realized from these developments. In this paper we describe a case study examining the potential for induced trips at mixed-land-use developments, utilizing survey data obtained from travelers at a typical mixed-use development site in Texas, USA. The remainder of this paper is organized as follows. In section 2 we review the literature on the topic of mixed-use developments and induced trips, demonstrating the gap to be filled by this research. Next, we outline the research problem and raise concern about the impact of induced trips in the mixed-use environment on the traffic-impact study process. In section 4 we describe the case-study site and provide details of the traveler survey and data collection. In section 5 we present the analysis results, which focus on induced travel by land use and also by travel mode. An estimate of the impact of vehicle miles traveled (VMT) is also provided in this section. Finally, we conclude the paper with a discussion of the impact of induced trips at mixed-use developments on regional-level and site-level planning practice, as well as implications for land-use policy making.

2 Mixed-use developments and induced trips

The theoretical foundations of induced travel are well documented in the literature. Downs (1992) proposed that the decreased cost of travel resulting from increased freeway capacity elicited short-run traveler response in the form of increased travel demand primarily through the shifting of vehicles from alternate routes to the freeway, travel from the shoulder periods to the peak periods, and travelers from public transportation to personal vehicles. In addition to Downs’s ‘triple convergence’, Lee et al (1999) included destination shifts (travelers selecting
a different destination for their trips based on a change in travel cost) and additional travel by current facility users as other sources of induced travel.

These concepts can also be used to consider the travel characteristics of neotraditionally designed mixed-use developments. In this environment, travelers could realize a saving in their cost of travel by remaining internal to the site for some trips (which generally costs less than travel outside the site) and by using the pedestrian-oriented streets that facilitate walking for many on-site trips (which can cost less than driving, over the distances usually found within these developments). The result of these travel-cost savings by travelers in the mixed-use environment may be an increased number of trips. Therefore, individual component land uses within a particular mixed-use development may actually generate more trips than their single-use, conventionally designed counterparts. These issues were first acknowledged by Crane (1996), who developed a conceptual framework for considering the possibility of induced tripmaking at mixed-use developments. Using a utility-maximization approach, Crane’s framework related the impact of three design elements of the neotraditional mixed-use environment (the grid street network, traffic calming, and mixed land uses) to three relevant measures of vehicle traffic (car trips, VMT, and the car mode split). Mixing land uses and increasing land-use density, Crane hypothesized, had three potential impacts on automobile travel. First, mixed use allows for more to be accomplished with a single trip, thus reducing the amount of travel required to obtain a given set of goods, in turn reducing the demand for car use. Second, mixed use reduces the marginal cost of all trips beyond the first trip, with the effect of increasing car use. Finally, higher development densities could increase congestion, thus increasing trip times, in turn reducing car use. The net effect of the three impacts, Crane argued, is dependent on trip purpose, trip length, and induced congestion. Crane hypothesized that only the traffic-calming elements of neotraditional neighborhood design would contribute to an overall reduction in automobile travel and further hypothesized that the grid street network, as well as the combined impact of the three elements together, could either increase or decrease automobile travel, not absolutely decrease it as had been assumed by conventional thinking. Crane and Crepeau (1998) tested this framework with empirical data from San Diego, CA and concluded that the more mixed land use (measured by the share of commercial land uses in residential tracts) was positively associated with the frequency of car trips for nonwork purposes among tract residents.

One important concept for our present case study, as noted by Cervero (2003), is that induced trips are considered to be either redistributive or generative in nature. The redistributed component is comprised of travelers already in a given travel market who are simply altering their travel behavior in response to a system change. Examples of such altered behavior might include a shift in route, time of travel, or travel mode. The generative component consists of new trips, previously suppressed but undertaken now that conditions in the travel market are more favorable. The generative component includes both new, additional trips generated by existing travelers as well as trips made by travelers who were previously not in the travel market. The key to understanding the impact of induced trip making at mixed-use developments is the question of redistribution or generation of such trips. That is, are internal walking trips at mixed-use developments replacing (redistributing) travel in automobiles on the external street network, or are new trips being generated over and above the baseline number of trips that would already have occurred? Past research has focused primarily on the redistributive effects of the shift of trips from automobile to walking (Cervero and Radisch, 1996; Shay et al, 2006). The issue of redistribution or the generation of new trips with respect to internal trips (regardless of mode) is slightly less clear. As part of a study on pedestrian behavior and attitudes in six Austin, TX neighborhoods, Handy (1996) surveyed residents about their most recent walk to the grocery store with respect to what the resident would have done if walking was not an available option for that trip. Across the three neighborhood types (traditional, early modern, and late modern), more than two thirds of the respondents
would have driven to the store, suggesting that many of these walking trips to the store were indeed substitutes for driving trips. Furthermore, approximately one in eight of the respondents in Handy’s study reported that they would have stayed at home rather than walk to the store, implying that the opportunity to walk to the store actually induced some pedestrian trips within the neighborhood. McCormack et al (2001) suggested that mixing land uses could make shopping activities more convenient, which would allow more time for additional travel. Collectively, these findings suggest that at least some of the trips in the mixed-use environment are induced and not redistributed from the external roadway network. Past studies on this topic are lacking in two distinct areas. First, they typically focus on larger neighborhoods or communities which rely on variations in the degree of land-use mixing and pedestrian infrastructure to prove their points. Second, past studies have typically utilized data from region-wide household travel-diary surveys in their analyses, which may be limited in data specifically from mixed-use development sites.

3 Research problem
Some research has suggested that placing several high-traffic origin–destination pairs within the same development will reduce vehicle traffic by internalizing some trips. Further, given the pedestrian-oriented design of mixed-use developments, some internal trips will be made on foot rather than in an automobile. However, because of the reduced travel costs realized by travelers at a mixed-use development, it is possible that new internal trips may be generated; these internal trips are not substitutes for external travel, but, rather, they are extra induced trips. Thus, a better understanding of the proportion of trips that are induced by the travel cost-saving elements of the mixed-use environment is desired. These induced trips also have implications for the techniques used by planners to evaluate the traffic impacts of proposed mixed-use development sites. One approach for estimating the number of trips generated by a proposed mixed-use development site implicitly assumes that all internal trips at the site are ‘capturing’, or replacing trips on the external street network (Institute of Transportation Engineers, 2004). However, some internal trips may be new trips (ie, the generative component of induced travel), that are not replacing or redistributing travel from the external street network. If new trips are being generated, they must be considered in the site planning process so that the transportation network adjacent to a proposed mixed-use development site can be adequately sized for the anticipated traffic demand.

4 Data and methods
The concepts of induced travel and a limited amount of past research have suggested that the travel-cost savings realized form the convenience of a complementary, interactive land-use mix and the proximity of these land uses in a mixed-use development induces travelers to make additional internal trips with the same travel ‘budget’. These are trips that would not have been undertaken if additional costs, such as off-site travel between single-use sites, were necessary. The decision to make additional trips within a mixed-use development is an individual behavior. Therefore, the best method to determine the extent of induced trips is to conduct a survey and specifically ask travelers at a mixed-use development about the induced nature of their trip.

4.1 Description of the case-study site
The mixed-use development site selected for this case study was located in Plano, TX, a northern suburb of Dallas. The site was located near the intersection of major regional expressways and wholly contained within a low-density large suburban office park which contained numerous corporate headquarters and varying-sized office buildings. The context of the study site is shown in figure 1 with the study site outlined. A site plan showing the land-use mix at the case-study site is shown in figure 2. The northern half of the site was mostly a mixed commercial area of retail, restaurant, and cinema in a town center configuration,
Figure 1. Aerial view of the case-study site (outlined) and its context.

Figure 2. Site plan of the case-study mixed-use development project.
with smaller offices and residential apartments above the ground-level retail and restaurant facilities. Retail properties included specialty retail shops, service-oriented businesses, and convenience stores.

On-site restaurants ranged from high-turnover sit-down restaurants to low-turnover upscale restaurants. In addition to the offices above the ground-level retail and restaurant facilities, three free-standing midrise office buildings were also located on the site. The entire southeast quarter of the site contained high-end multifamily apartment buildings or single-family townhomes. Finally, near the center of the site was an upscale conference hotel fronted by a large park-like open area. A more detailed description of each of the case-study site elements can be found in table 1. All development data were unpublished data provided by the applicable developer or management entity and were representative of the site at the time of the survey.

**Table 1.** Description of case-study site elements.

<table>
<thead>
<tr>
<th>Site element</th>
<th>Quantity</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole site</td>
<td>75 acres (30.4 ha)</td>
<td>suburban mixed-use development, approximate dimensions 1600 ft × 1200 ft (488 m × 366 m), maximum diagonal travel distance 2000 ft (610 m)</td>
</tr>
<tr>
<td>Office</td>
<td>580 433 ft² (53 980 m²)</td>
<td>310 764 ft² (28 901 m²), occupied: 53.5%, three midrise office buildings, upper-floor office above retail/restaurant</td>
</tr>
<tr>
<td>Retail</td>
<td>205 158 ft² (19 080 m²)</td>
<td>196 264 ft² (18 253 m²), occupied: (95.7%), one large furniture store: 93 000 ft² (8649 m²), 40 smaller clothing, convenience, and specialty shops</td>
</tr>
<tr>
<td>Restaurant</td>
<td>69 318 ft² (6447 m²)</td>
<td>all restaurant properties occupied, coffee shop and juice bar open in morning, variety of restaurants open during midday and evening</td>
</tr>
<tr>
<td>Residential</td>
<td>1512 units</td>
<td>1449 apartment units, 63 townhomes, approximately 90% occupancy, apartments, stand-alone buildings, or above retail/restaurant</td>
</tr>
<tr>
<td>Cinema</td>
<td>5 screens</td>
<td>total 1019 seats, largest auditorium 299 seats, generally independent or foreign films</td>
</tr>
<tr>
<td>Hotel</td>
<td>404 rooms</td>
<td>full-service, upscale conference hotel, 32 000 ft² (2976 m²) conference and meeting space</td>
</tr>
<tr>
<td>Parking</td>
<td>6070 spaces</td>
<td>garages: 77%, surface: 17%, street: 6%, 3914 spaces: 64.5% reserved for employees/residents, nonreserved spaces free of charge to visitors</td>
</tr>
<tr>
<td>Transit</td>
<td>–</td>
<td>one crosstown suburban bus route stop on southern edge, weekdays only, 40–60 min headways</td>
</tr>
</tbody>
</table>

The following attributes made the case-study site an ideal setting to examine the potential for induced trips at mixed-use developments:

- **Land-use mix:** there were six distinct and complementary land uses at the case-study site, creating multiple opportunities for travel with both trip ends (origin and destination) within the development. Additionally, the land-use mix was interactive; that is to say, the land uses present created origin–destination pairs that would logically have some level of interaction, such as restaurant and cinema.

- **Grid-style street layout:** the arrangement of the streets at the site resembled a partially offset grid layout consistent with typical mixed-use development design, as shown in figure 2. While it was not a completely continuous grid system, there was sufficient connectivity to facilitate internal travel and allow travelers to select from several routes for travel through the development.
● Pedestrian-supportive design: the maximum walking distance at the site, approximately 2000 ft (610 m), did not impose any restrictions on those desiring to travel on foot. The streetscape accommodated the pedestrian by offering wide sidewalks, shade trees, and benches. Additionally, pedestrian safety was enhanced by traffic-calming measures such as speed humps, offset intersections, and bulb-outs, as well as by on-street parking creating a buffer between moving vehicles and pedestrians.

One attribute of the case-study site that is inconsistent with modern mixed-use development design was the lack of accessibility of the site for nonautomobile travelers. The long headways of the single bus route serving the site made transit an unattractive choice for travelers who might have an option, and the site’s location within the larger business park (large parcels of land and a conventional street system) made walking to the site impractical from most locations. However, as will be demonstrated in the following section, this issue was actually a benefit to the goals of the study. Beyond the concerns about external transit and pedestrian accessibility, the study site sufficiently emulated characteristics of typical urban mixed-use development design for the findings of this case study to be applied across a broad range of mixed-use developments that share these characteristics.

4.2 Survey design

Because the decision to travel is inherently a choice made at the individual level, data for this case study were required to be obtained via a personal interview survey of travelers at the case-study mixed-use development site. An origin–destination intercept survey administered by trained data-collection personnel to persons as they exited buildings at the study site was used to obtain data for this research. Data-collection personnel were instructed to obtain as many completed interviews as possible from travelers exiting doors in designated locations in a systematic manner, approaching the next person that exited their assigned building immediately following a completed interview. Interview locations were selected in order to obtain interviews at all six on-site land uses and to ensure a spatial distribution of interviews from different units within a particular land use. Information obtained for the traveler survey included the destination of the trip, the location of this destination (either internal to the study site, or external), and the mode of travel for the trip. No demographic data were collected, as such questions would have made the interview unduly long and the response to such questions may have been limited due to the public setting of the interviews. If the destination end was identified as internal to the study site, a follow-up question about the possible induced nature of the trip was asked, as follows:

“Would you be making this trip if you had to travel outside of <study site name>?”

This question attached a cost (of hypothetical travel outside of the case-study site) to the trip the respondent was making at the time of the interview, and asked that individual to consider if he or she would have made the trip even if faced with this additional cost. A ‘yes’ answer to this question indicated that the trip was not induced because the respondent would have been willing to make the trip either within or outside the site, presumably regardless of the difference in travel costs. In this case, the internal trip was assumed to be replacing or redistributing a trip from the external street network. A ‘no’ answer to the question suggested that the respondent was making an induced trip (more specifically, a ‘generated’ induced trip) because the marginal cost to travel outside the site (either real or perceived) was higher than the respondent valued the trip. One potential issue influencing the responses to this question that needed to be addressed was the presence of competing opportunities around the study site. For example, if a location similar to the respondent’s internal destination was available across the street from the study site, the marginal cost of traveling outside the site would be low and travelers would not encounter much resistance to traveling outside the site to reach their destination. Conversely, if the closest similar opportunity was farther away, making an internal trip would be comparatively more advantageous. This was not explored in detail as
part of this case study and is recommended for future research. However, the study site’s location inside a large suburban office park meant that a drive of at least several minutes would be required for travel to other sites where similar services were available (recall the issue of pedestrian and transit accessibility to the site from external locations discussed previously). It should be noted that this question asked the respondent to predict their travel behavior in a hypothetical situation (stated-preference scenario) and is therefore subject to the potential bias and inaccuracy that are inherent to such questions.

4.3 Data collection
Before initiating data collection, we contacted the study site’s developer and management company to obtain their permission to conduct our study on their property and to gather detailed information about the on-site land uses. Additionally, since the research involved interaction with human subjects via one-on-one interviews, we secured human subjects research approval from the Texas A&M University Institutional Review Board before starting data collection. Traveler interviews were conducted at the site during weekdays in late May 2007. Data collection occurred during two periods, 6:00 am – 10:00 am and 3:00 pm – 7:00 pm. Given the large size of the site and the number of personnel available for data collection, morning and afternoon study periods over two days were necessary to collect sufficient data across the entire site. In addition to the travel-survey interviews, counts of persons entering and exiting survey locations were recorded to determine the population size from which the interview respondents were drawn. Data collection during the morning study period yielded a total sample of 340 trips, which represented approximately 18.4% of the 1846 total person trips that exited locations at the study site. Response rates by land use during the morning study period ranged from 12% (office and hotel) to 23% (residential). During the afternoon study period, 453 trips were obtained from the traveler interviews, which represented approximately 15.8% of the 2871 person trips that exited locations at the study site. Response rates by land use during the afternoon study period ranged from 10% (restaurant) to 47% (cinema). The response rate for the induced-travel question was 69.8% of survey participants in the morning study period and 94.0% for the afternoon study period.

4.4 Analysis methodology
Each trip obtained from the traveler interviews consisted of the following elements: origin land use, destination location (internal or external to the study site), destination land use, and the mode of travel for the trip. For internal trips, the trip record also contained a response to the induced-travel question. The survey data were entered into a computer spreadsheet for analysis. For each study period, an origin–destination matrix was developed that grouped trips of similar on-site origin and destination land use (or external destination, as appropriate). Grouping trips by origin land use was necessary to ensure a sufficient sample size for analysis, which would not have been possible if the data were grouped at the level of an individual building, establishment, or business. The values in this matrix were then weighted to reflect the sampling rates for each individual land use as well as the contribution of components of each on-site land use where no data collection took place. A similar process was utilized to develop an expanded origin–destination matrix, by study period, for the induced-travel data only.

5 Results
Preliminary analysis of the survey data found that at least some proportion of the internal trips at the case-study site in both the morning and afternoon study periods were identified as induced. During the morning study period, a total of 2823 person trips exited locations at the site, of which 434 (15.4%) were internal to the site and 111 (3.9%) were induced. Induced travel comprised about 25.6% of the internal trips, meaning about 25% of internal trips were reported to be additional trips, and not replacements for trips that would have
otherwise used the external street system. In the afternoon study period, a total of 4577 person trips exited locations at the case-study site, of which 2012 (44.0%) were internal to the site and 1024 (22.4%) were reported to be induced. About half of the internal trips (50.9%) at the case-study site were reported to be induced trips and were not ‘captured’ from the external street network. The induced-travel percentage for the afternoon was higher than that for the morning. One explanation for this could be that travelers in the morning had other activities that they needed (or wanted) to do besides making additional trips at the case-study site. Alternatively, the difference could be attributed to a lack of competing opportunities available during the morning period.

Although travelers were not specifically asked why they would or would not make a trip outside of the case-study site as part of the travel survey, it is implied from induced-travel theory and literature that the presence of multiple on-site land uses, the ability to walk for some trips instead of driving, or a combination of the two are the primary characteristics that compel travelers to make additional trips in the mixed-use environment. As such, more detailed analyses of the survey data in this case study were focused on induced trips between land-use pairs at the case-study site and the relationship between induced travel and travel-mode choice.

5.1 Land-use analysis

In the mixed-land-use environment, the primary catalyst of induced trips is the presence of multiple land uses within a single development site, which allows travelers to make additional trips within the site without substantial marginal investment in travel cost. The following question is then raised: which land-use pairs will generate these induced trips? Analysis of the survey data in this case study provides a starting point for answering this question. The percentage of internal trips that were induced by land-use pairs for each study period is shown in table 2. These values represent the percentage of internal trips for a given land-use pair that was newly generated and not ‘captured’ from the external street network.

Table 2. Percentage of induced trips by land-use pair.

<table>
<thead>
<tr>
<th>Origin</th>
<th>Destination</th>
<th>office</th>
<th>retail</th>
<th>restaurant</th>
<th>residential</th>
<th>cinema</th>
<th>hotel</th>
<th>all trips</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Morning study period (6.00 am–10.00 am)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office (n = 9)</td>
<td>100.0</td>
<td>–</td>
<td>0.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>66.7</td>
</tr>
<tr>
<td>Retail (n = 24)</td>
<td>0.00</td>
<td>–</td>
<td>–</td>
<td>35.7</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>13.5</td>
</tr>
<tr>
<td>Restaurant (n = 99)</td>
<td>18.2</td>
<td>0.0</td>
<td>–</td>
<td>0.0</td>
<td>–</td>
<td>–</td>
<td>100.0</td>
<td>14.5</td>
</tr>
<tr>
<td>Residential (n = 160)</td>
<td>0.0</td>
<td>50.0</td>
<td>59.6</td>
<td>12.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>25.6</td>
</tr>
<tr>
<td>Cinema</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Hotel (n = 48)</td>
<td>0.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>Afternoon study period (3.00 pm–7.00 pm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office (n = 80)</td>
<td>0.0</td>
<td>–</td>
<td>0.0</td>
<td>0.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>0.0</td>
</tr>
<tr>
<td>Retail (n = 72)</td>
<td>0.0</td>
<td>67.1</td>
<td>71.9</td>
<td>80.0</td>
<td>–</td>
<td>–</td>
<td>50.0</td>
<td>68.4</td>
</tr>
<tr>
<td>Restaurant (n = 94)</td>
<td>50.0</td>
<td>66.7</td>
<td>44.8</td>
<td>16.8</td>
<td>0.0</td>
<td>–</td>
<td>33.3</td>
<td>36.0</td>
</tr>
<tr>
<td>Residential (n = 105)</td>
<td>32.5</td>
<td>50.6</td>
<td>56.4</td>
<td>41.5</td>
<td>–</td>
<td>50.0</td>
<td>–</td>
<td>46.3</td>
</tr>
<tr>
<td>Cinema (n = 51)</td>
<td>–</td>
<td>75.0</td>
<td>50.0</td>
<td>0.0</td>
<td>–</td>
<td>–</td>
<td>0.0</td>
<td>47.9</td>
</tr>
<tr>
<td>Hotel (n = 51)</td>
<td>–</td>
<td>100.0</td>
<td>77.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>81.5</td>
</tr>
</tbody>
</table>

Notes: – indicates that no internal trips were observed for this land-use pair. Values shown in bold were derived from percentages of induced and internal trips that were obtained from a statistically significant sample size with a margin of error of 10% at α = 0.05. Cinema was not open to the public during the morning study period.
During the morning study period, significant induced-travel activity was focused on the restaurant land (approximately one of every seven internal trips induced) and the residential land use (one in four internal trips induced). Half of the internal trips from residential to retail land use were reported to be induced, as were nearly 60% of the trips from residential to restaurant land use. This suggests that while the residents of the mixed-use site were making internal trips to these routine morning destinations, more than half of these trips were made simply because the presence of the retail shops (a convenience store and dry cleaners) and restaurants (coffee shop, bakery, and juice bar) at the study site made these trips more attractive to those travelers. No internal trips between restaurant and retail, restaurant and residential, and residential and office land-use pairs were induced, indicating that the internal travel between these land uses were replacements for travel outside the site.

Analysis of the afternoon study period data indicates that a significant amount of induced travel was occurring at a majority of the land-use pairs at the case-study site. Significant induced-travel activity occurred between the retail and restaurant land uses, between which approximately two thirds of the internal trips were induced. Additionally, about two thirds of the trips between individual retail establishments were induced. Intuitively, these findings make sense, given the high amount of interaction one might expect to find between retail shops and restaurants. Nearly half of all the internal trips originating at the residences and the cinema were induced. One land use where no induced trips originated was the office, where trips with destinations of other offices, restaurants, or on-site residences were captured from the external street network. It is also noted that there were no induced trips with the cinema as the destination. While this might not have been the case for a mainstream, multiplex-style movie theater, the cinema at the case-study site generally featured independent or foreign films which were less likely to induce travelers to the cinema. Depending upon the destination land use, internal trips originating at a residence during the afternoon study period were induced from 30%–60% of the time. Much like the morning study period, residents of the case-study site were active in generating new internal trips during the afternoon study period.

5.2 Travel-mode analysis

Another question of great interest is whether or not travelers respond to the pedestrian-oriented elements of the mixed-use environment by substituting walking trips for driving trips. In the context of this case study, the pedestrian-friendly environment of mixed-land-use developments may induce additional walking trips within the development that would not have taken place if the trip had originated in a conventionally designed, single-land-use setting where off-site vehicular travel was required for travel between destinations. Analysis of the travel-survey data revealed that all the internal trips in the morning study period and virtually all those in the afternoon study period were made by automobile (as a driver or a passenger) or on foot. This was expected as no opportunities for internal travel on transit systems existed at the study site. The percentage of all internal trips made by each mode that were reported to be induced is shown in table 3. For example, of the 180 estimated internal trips made by automobile during the morning peak period, 17.2% were reported as being induced.

<table>
<thead>
<tr>
<th>Travel mode</th>
<th>Morning</th>
<th></th>
<th>Afternoon</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>number</td>
<td>percentage</td>
<td>number</td>
<td>percentage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>induced</td>
<td>induced</td>
<td>induced</td>
<td>induced</td>
<td></td>
</tr>
<tr>
<td>Automobile</td>
<td>180</td>
<td>31</td>
<td>498</td>
<td>195</td>
<td>39.2</td>
</tr>
<tr>
<td>Walking</td>
<td>258</td>
<td>79</td>
<td>1517</td>
<td>824</td>
<td>54.3</td>
</tr>
</tbody>
</table>

Note: Automobile includes travel as driver or passenger.
The practical interpretation of table 3 is that an internal trip made on foot appears more likely to be induced than an internal trip made by automobile. This finding seems to support the notion that travelers respond to the ability to walk in the mixed-use environment by generating additional walking trips. Because the values in table 3 represent the percentage of internal trips by mode that would not have been taken if the trip’s destination was located outside the study site, it could be implied that the balance of the trips for each mode were substitutes for trips outside the site. For automobile trips, approximately 83% of the internal trips in the morning and about 60% of those during the afternoon were replacements for trips on the external street network. The replacement percentages were lower for walking trips, with about 70% of internal walking trips in the morning and about 45% of those in the afternoon estimated to be replacements for trips outside the study site. It was noted previously that nonautomobile access was a characteristic of the study site that may have limited modal diversity and choice in the travel survey. However, for the travel-mode analysis, it could also be said that the vast majority (>90%) of the external trips were made by automobile (this was also supported by the mode split of external trips in the travel survey). Thus, it could be argued that at least 90% of the walking trips internal to the site that were replacing trips outside the site were replacing an automobile trip with a walking trip. This finding supports the conventional wisdom that walking trips within mixed-use development sites are replacing automobile trips outside the site.

5.3 WMT analysis

At the regional level, planners are concerned primarily with developing, maintaining, and programming transportation network improvements across an entire urban area or region. One measure used by regional planners to evaluate potential network improvements is VMT. VMT provides a measure of the quantity of travel in an urban area and is tied to measures of energy consumption, air quality, and other environmental concerns. While no formal statistical analyses were performed on the travel-mode element of the survey, the findings in table 3 can be used to perform a ‘back of the envelope’ calculation of VMT for the case-study site as it existed and a hypothetical conventionally designed site.

Components of the VMT for the case-study site included both internal and external vehicle trips. Lacking empirical data on average vehicle-trip lengths for the region, we assumed the average internal vehicle trip was 0.25 miles in length and the average external vehicle trip into the region was 5 miles in length. Using these averages, a total VMT could be calculated based on the trips taken at the study site (see table 4). For the case-study site, vehicle miles included all external vehicle trips as well as all internal vehicle trips, regardless of whether or not the trip was reported as induced. Internal trips using nonmotorized travel modes (walk or bicycle) were not included as these trips are local in scale and typically are not of interest to regional planning and modeling. For a hypothetical conventional development, vehicle miles included those trips respondents indicated were external vehicle trips, noninduced internal vehicle trips, and walk trips that were assumed to be external vehicle trips in the single-use site scenario. The same average trip distances were assumed for the hypothetical site.

With these assumed trip lengths, the case-study site contributes approximately 14.2% fewer VMT in the morning compared with a hypothetical conventional development, and 34.3% fewer VMT in the afternoon (see table 4). On the basis of these ‘back of the envelope’

Table 4. Vehicle miles traveled (VMT) comparison between case-study site and hypothetical conventional development.

<table>
<thead>
<tr>
<th>Development scenario</th>
<th>Morning study period VMT</th>
<th>Afternoon study period VMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing (case-study site)</td>
<td>10 273.5</td>
<td>11 637.5</td>
</tr>
<tr>
<td>Alternate (conventional site)</td>
<td>11 480.0</td>
<td>16 460.0</td>
</tr>
<tr>
<td>Percentage difference</td>
<td>14.2</td>
<td>34.3</td>
</tr>
</tbody>
</table>
calculations, it is evident that VMT savings are realized at mixed-use developments, even in light of the VMT contribution of induced vehicle trips inside the site. This saving appears due, in large part, to the replacement of automobile trips outside the study site with walking trips inside the site. It is noted that the ‘breakeven’ assumed external vehicle-trip length (that is, the minimum length at which a VMT saving would be realized) is approximately 0.125 miles for both study periods. Therefore, while the calculations shown in table 4 were based on external vehicle trips assumed to be 5 miles in length, a VMT saving is realized with an assumed external trip length >0.125 miles. As assumed driving distances increase, the VMT savings (and the associated benefits) increase accordingly.

6 Discussion and conclusions
The case study described in this paper, which was inspired by Crane’s (1996) challenge to conventional thinking about the travel impacts of neotraditional mixed-use developments, examined the potential for induced trips at mixed-use developments. However, our approach represents a departure from other examinations of this issue (eg, Boarnet et al, 2011; Crane and Crepeau, 1998; Greenwald, 2003) which focus primarily on comparing macrolevel measures of travel behavior across multiple larger neighborhood types, typically using household travel-diary survey data. Furthermore, to the authors’ knowledge, the use of stated-preference-type data in this context is unique, with the only known study which utilized a similar approach being the one of Handy (1996). We utilized stated-preference-type data from travelers, obtained during the course of a trip being undertaken by the traveler at a fully integrated and functioning mixed-use development project, and subsequently demonstrated that approximately 25% of morning trips and 50% of afternoon trips within the case-study site are newly generated, and would not otherwise have occurred if the destination was located outside of the case-study site. However, even with these induced trips, a reduction in overall automobile travel (measured by VMT) was still realized at the case-study site, as compared with a hypothetical conventionally designed site.

Having established that some induced trips occur in the mixed-use environment, we now examine the impact of these induced trips on how the planning profession and others evaluate the traffic impacts of mixed-land-use developments. On the surface, it would appear that the transportation effects of induced travel at mixed-use developments are minimal, due to the act that these extra trips never enter the external transportation network. However, while the findings reported here represent the outcome of a single case study, there are several contributions made by this study to transportation planning as well as land-use policy.

On the site-planning level, the findings of this case study impact the techniques used by planners to develop traffic-impact studies for proposed mixed-use sites. One methodology for estimating trip generation at mixed-land-use developments, recommended by the US Institute of Transportation Engineers, involves estimating trip generation for each component land use at the proposed mixed-use site as a single-use site, then applying a set of recommended internal trip-capture percentages to this estimate to compute the total number of internal and external trips expected at the site (Institute of Transportation Engineers, 2004). However, implicit in this methodology is that all trips between two on-site land uses are ‘captured’ from the external street network. As this case study has shown, not every trip between two on-site land uses is redistributed from transportation networks outside the site—some new trips are being generated. Therefore, practitioners who are tasked with conducting a traffic-impact analysis for a proposed mixed-use development project are encouraged to consider these findings, in tandem with other studies of travel behavior at mixed-use developments and their own professional judgment, to develop a trip-generation estimate for the proposed site that acknowledges the possibility of induced trips as a result of travel-cost savings realized in the mixed-use environment.
From a policy perspective, the idea that mixed-use developments could actually generate more trips than conventional developments complicates the situation faced by those exploring land-use solutions to urban traffic congestion issues. From this case study, it is evident that some of the internal trips at mixed-use developments are not ‘captured’ from the external street network, but represent additional trips, induced by the characteristics of the mixed-use environment that reduces overall travel costs. However, it is shown that even with induced vehicle trips, VMT savings can be realized from land-use policies that promote high-density, pedestrian-friendly mixed-use developments. It should be emphasized that the existence of induced trips in the mixed-use environment is not necessarily a bad thing; after all, what is wrong with building places that provide a vibrant pedestrian atmosphere and the opportunity for travelers to get out of their cars? Increased local trip making reflects an improvement to the quality of life, enriches the civic fabric of a community by enhancing the opportunities for social interactions, and can enhance health by increasing physical activity durations through additional trip making, primarily on foot. Induced travel certainly benefits development companies and commercial tenants, who appreciate the extra traffic and revenue potential; local jurisdictions gain from increased sales-tax receipts and improved property values. In an era when we have begun to expect new developments to accomplish more than simply accommodating traffic demands, the ability to increase physical activity and civic engagement may be even more meaningful than simple reductions in the number of external vehicle trips. Thus, while induced trips may potentially undermine the trip reduction benefits calculated in traffic impact studies, the increase in traffic due to induced travel has a host of positive nontransportation-related benefits while still contributing to an overall reduction in VMT. Therefore, from a policy perspective, the development of mixed-use sites should remain in the toolbox of solutions to combat traffic congestion and related issues.

Given the limited quantity of data and research that exists on traveler behavior at mixed-use developments, future work in this area is needed. More detailed studies should be undertaken to identify what factors of the mixed-use environment exert the greatest influence on induced travel. With the popularity of transit-oriented mixed-use developments, an evaluation of transit riders and induced travel would be of benefit to many disciplines of the planning community. Another aspect of this question that would be an excellent topic of future work is the role of self-selection on induced trips at mixed-use sites. Do residents of these sites live there due to the fact they like to take frequent walking trips to internal destinations? The issue of self-selection also extends to visitors and workers at a mixed-use development site; for example, are travelers actually traveling more miles to visit places like the case-study site, where many walking trips can be chained together with a single vehicle trip? Furthermore, the regional destination aspect of mixed-use centers may in fact attract new trips from across the region by travelers wanting to enjoy the neotraditional setting that otherwise might not be available. Are employment opportunities within the mixed-use development more attractive because of the surrounding environment? Trip-length information for internal and external trips would be ideal; adding a question to the intercept survey to ascertain trip distances would be useful for future surveys and could provide a more accurate assessment of the VMT implications of mixed-use developments. Finally, the intercept survey could be enhanced by adding sociodemographic variables, which would support more in-depth modeling efforts. Future studies in these areas will no doubt be able to advance the work of this study; until then, the planning community must approach mixed-use developments in a very deliberate and comprehensive manner, including the potential for induced travel to ensure that the transportation impacts of these developments are properly identified.

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References


Frank L, Pivo G, 1994, “Impacts of mixed use and density on utilization of three modes of travel: single-occupant vehicle, transit, and walking” *Transportation Research Record* number 1466, 44 – 52

Freidman B, Gordon S, Peers J, 1994, “Effect of neotraditional neighborhood design on travel characteristics” *Transportation Research Record* number 1466, 63 – 70


Handy S, 1996, “Urban form and pedestrian choices: study of Austin neighborhoods” *Transportation Research Record* number 1552, 135 – 144

Institute of Transportation Engineers, 2004 *Trip Generation Handbook* 2nd edition (Institute of Transportation Engineers, Washington, DC)


Lee D, Klein L, Camus G, 1999, “Induced traffic and induced demand” *Transportation Research Record* number 1659, 68 – 75


Walters G, Ewing R, Schroer W, 2000, “Adjusting computer modeling tools to capture effects of smart growth, or ‘poking at the project like a lab rat’” *Transportation Research Record* number 1722, 17 – 26

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