# MULTI-MODAL TRIP GENERATION FROM LAND USE DEVELOPMENTS: INTERNATIONAL SYNTHESIS AND FUTURE DIRECTIONS

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## ABSTRACT

Trip generation estimates are integral to assessing the transport impacts of land use developments. However, past efforts have predominantely focused on vehicle trips only. This paper provides an international literature review of multi-modal trip generation associated with land use developments. A total of 153 publications were sourced as relevant to the review. The results show that while multi-modal trip generation studies have been relatively scant, they have received greater attention in the last 10 years. A range of issues were identified with estimating and applying multi-modal trip generation rates, not least was a lack of sufficient data and higher complexity in data collection compared to vehicle trip generation studies. Current knowledge gaps highlight opportunities to move towards greater international coordination and sharing of multi-modal trip generation data, along with exploring the use of technology to assist with data collection. Key directions for the future include a fundamental change in paradigm to consistently account for multi-modal trip generation, the development of an international multi-modal trip generation database, and greater sensitivity testing in assessing the multi-modal impacts of new land use developments.


*Keywords*: trip generation, multi-modal, land use, transport impact assessment, new development

## INTRODUCTION

A key element in preparing a Transport Impact Assessment (TIA) for a proposed land use development involves estimating the number of trips likely to arise from the development, a process known as 'trip generation'. Trip generation estimates are arguably the most important input to a TIA as they inform the scale of transport impacts associated with new development and the measures that may be needed to manage those impacts (*1*). While best practice promotes the use of multi-modal trip generation estimates – that is, the number of trips generated by each transport mode – practice is still largely predicated on estimating vehicle (automobile) trips only (*2*). A sole focus on vehicle trips can lead to inadequate provision of infrastructure to facilitate walking, cycling and transit use. It can also limit the consideration of emerging transport technologies and related services, e.g. paratransit, electric scooters, bike share systems, mobility as a service. This can have negative consequences for liveability, health and environmental outcomes in cities, and can also lead to increased development costs through the overdesign of motor vehicle infrastructure (*3*).

A shift has been occurring in recent years towards greater consideration of non-automobile modes in the TIA process, particularly for land use developments in highly urbanised areas (*4-7*). The consideration of multi-modal trip generation is integral to these efforts, yet there is no published synthesis of the literature on this topic. While Currans (*8)* provides a detailed review of issues with trip generation 'methods', the research is exclusive to techniques developed using data from the United States. This paper therefore aims to take a broader perspective through presenting an international synthesis of the literature, but with a focus on multi-modal trip generation. Specific objectives of the research are:

1. To understand methods used to collect multi-modal trip generation data
2. To synthesise current and past practice in the consideration of multi-modal trip generation
3. To identify issues associated with estimating and applying multi-modal trip generation rates
4. To identify key knowledge gaps in the field and opportunities for future research.

This paper contributes to the literature by providing an international review of multi-modal trip generation practices associated with land use developments. Based on this insight, the paper also suggests a number of directions to guide future practice and policy in the field. This paper is focused on trip generation at the site level, rather than the process within four-step travel demand models which is a separate topic and does not typically consider the built environment at the local scale (*9*).

This remainder of this paper is structured as follows. The next section describes the research method used to source and analyse publications for the review. This is followed by the results, structured in line with each research objective. The paper then concludes with a summary of key findings and a discussion of future directions.

## RESEARCH METHOD

To meet the aim and objectives of this research, a literature review of relevant publications in the field of multi-modal trip generation was undertaken. In addition to a general internet search, the following key databases were used to source publications for the review: ScienceDirect, Scopus, and Transportation Research International Documentation (TRID). The Institute of Transportation Engineers (ITE) online library was also used given its wide coverage of trip generation studies. When searching for relevant publications, combinations of the following search terms were used: *trip generation*, *traffic generation*, *trip rate*, *traffic impact*, *transport impact*, *multi-modal*, *multimodal*, *land use development*, *urban development*, and *new development*. No restriction was placed on the geographical location or year from which relevant literature was sourced. However, the search was limited to English-language publications only, which may have limited the amount of literature sourced from non-English speaking countries.

Following an initial scan of each publication, additional literature was identified through 'backward referencing' where the list of references in each publication was reviewed. This was followed by a process of 'forward referencing' (using Google Scholar) which involved reviewing literature that was cited by the publications sourced initially (*10*). There were several instances of where a conference paper was later published in a journal with minimal change, or where multiple versions of a publication (e.g. guidelines) were available. In these cases, only the latest version was included.

A total of 153 publications were sourced that were considered relevant to trip generation in the context of land use development. Table 1 provides a breakdown by publication type and year. Across all publications, most were either journal articles (56%) or conference papers (24%). Slightly more than half of the literature was published from 2010 onwards (53%). Of the 153 publications, only 46 were specifically focused on multi-modal trip generation, providing the main basis for the literature review.

**TABLE 1 Literature Sourced for the Review by Year and Type of Publication**

| Year of Publication | Type of Publication | | | | | Total |
|---|---|---|---|---|---|---|
| | Journal Article | Conference Paper | Research Report | Consulting/ Other Report | Other (e.g. Guidelines) | |
| Pre 1990 | 8 | 3 | - | - | - | 11 (7%) |
| 1990-94 | 10 | 5 | - | - | - | 15 (10%) |
| 1995-99 | 7 | 10 | - | - | - | 17 (11%) |
| 2000-04 | 6 | 2 | - | - | - | 8 (5%) |
| 2005-09 | 11 | 6 | 2 | 1 | 1 | 21 (14%) |
| 2010-14 | 24 | 3 | 5 | 5 | 1 | 38 (25%) |
| Post 2014 | 20 | 8 | 4 | 3 | 8 | 43 (28%) |
| Total (%) | 86 (56%) | 37 (24%) | 11 (7%) | 9 (6%) | 10 (7%) | 153 (100%) |

In order to synthesise information across all relevant publications, a database was created with fields corresponding to the objectives of the literature review (e.g. methods, issues). Relevant data and information was then extracted from each publication and inserted into the database, with this analysed in qualitative terms and through the use of descriptive statistics.

## RESULTS

This section details the results of the literature review, structured in line with each research objective.

### Methods used to collect multi-modal trip generation data

Table 2 presents a summary of methods used to collect multi-modal trip generation data. A total of six methods were identified from the literature, including: manual vehicle count, automatic vehicle count, person count, intercept survey, household travel survey, and workplace/school travel survey.

Vehicle counts, undertaken either manually (method 1) or automatically (method 2), are capable of capturing all vehicle trips to/from a site but need to be used in conjunction with other methods to obtain an understanding of multi-modal trip generation. While person counts (method 3) typically capture all trips to/from a site, they can rarely be used in isolation to estimate trips by mode, particularly where site users walk to/from public transport stops or off-site parking areas that cannot be observed easily from the site (*11; 12*). In these cases, an intercept survey (method 4) is usually required to ask site users about their mode of transport to/from the site, with the opportunity often used to ask for other information such as trip purpose and socio-demographics (*13*). In more recent years, data from household travel surveys (method 5) has been used to estimate multi-modal trip generation (*14-16*), although relatively small sample sizes for transit and cycling trips can pose difficulties in developing trip generation estimates by these modes. Workplace/school travel surveys (method 6) have also been used to estimate trips by mode to employment and education sites (*17-19*), but generally contain a degree of non-response and so need to be scaled up based on total employee/student numbers or an independent person count (method 3).

In sum, unlike vehicle trip generation studies, a single method can rarely be used to accurately estimate multi-modal trip generation. This has implications for planning and administering multi-modal trip generation studies, particularly the cost associated with employing survey staff.

**TABLE 2 Summary of Methods for Collecting Multi-Modal Trip Generation Data**

| **Method** *(examples)* | **Description** | **Advantages** | **Disadvantages** |
|---|---|---|---|
| 1. Manual vehicle count (*13; 20; 21*) | Count of vehicles entering/exiting site through manual observation | • Cost effective for short time periods<br>• Does not require input from site users<br>• Capable of capturing all vehicle trips | • Not cost effective for long time periods<br>• Presence of multiple vehicle access points may require several surveyors<br>• Needs to be used with other methods to obtain multi-modal trip information |
| 2. Automatic vehicle count (*22-24*) | Count of vehicles entering/exiting site using automatic counters (e.g. pneumatic tubes) | • Cost effective for long time periods<br>• Does not require input from site users<br>• Capable of capturing all vehicle trips | • Not cost effective for short time periods<br>• Presence of multiple vehicle access points may require several automatic counters<br>• Needs to be used with other methods to obtain multi-modal trip information |
| 3. Person count (*11; 25; 26*) | Count of people entering/exiting site through manual observation | • Cost effective for short time periods<br>• Does not require input from site users<br>• Capable of capturing all person trips, and in some cases by travel mode | • Not cost effective for long time periods<br>• Presence of multiple vehicle access points may require several surveyors<br>• May need to be used with intercept survey to obtain trip information (e.g. mode) |
| 4. Intercept survey (*27-29*) | Survey of people entering/exiting site about key trip characteristics | • Cost effective for short time periods<br>• Captures information on trip characteristics (e.g. mode, purpose) and socio-demographics | • Not cost effective for long time periods<br>• Requires input from site users<br>• Represents sample only so typically needs to be used in conjunction with person count |
| 5. Household travel survey (*14-16*) | Survey of personal travel behaviour by households usually via travel diary | • Captures detailed information on trip making (e.g. mode, purpose, location) | • Requires input from households<br>• Small sample may limit estimation of trip generation for some modes (e.g. transit)<br>• High cost compared to other methods |
| 6. Workplace/ school travel survey (*17-19*) | Survey of employees/students about their travel to work/school | • Generally cost effective<br>• Can capture detailed information on trips (e.g. mode, timing) and socio-demographics | • Requires input from site users<br>• Represents sample only so typically needs to be scaled up based on employee/student numbers or through a separate person count |

*Source:* Author's synthesis of the literature



## Current and past practice in multi-modal trip generation

Table 3 provides a summary of trip generation studies reported in the literature, including their location (country), land use group, survey year/s, number of sites, survey method, transport modes, and the extent to which the surveyed vehicle trip generation rates differed from those published by the Institute of Transportation Engineers (ITE).

The majority of studies were found to be undertaken in the United States, although a range of other countries are represented throughout Australasia, Africa, Asia, Europe, North America, the Middle East and South America. While it is not possible to identify any clear pattern by country from Table 3, there appears to be very limited representation from mainland Europe. In part, this may be due to the literature search being limited to English-language publications only. However, Transport Impact Assessments (TIAs), while generally undertaken in countries such as Germany, Spain, Sweden, Slovenia and Poland, are typically part of a broader land use planning process (*30*) or wider environmental assessment procedure (*31*). In Italy, TIAs for individual developments are generally not undertaken, with impacts considered on a more area-wide basis (*32*). Practices such as these could potentially reduce the requirement for detailed site-specific trip generation rates in planning for new land use developments.

Most of the studies collected trip generation data for various land use groups, such as mixed use developments, particularly in more recent years (i.e. post 2010). Of those that collected data for a single land use group, representation was found across the following groups (from most to least common): residential, retail, institutional, services, recreational, office, lodging, terminal, and medical.

Studies were published between the years of 1982 and 2018, with data collection reported to be undertaken between 1976 and 2017. However, in several cases, the survey years were not reported so it is not possible to know the extent to which older data had been published. However, where survey years were reported, data collection was generally undertaken within 5 years of publication, and in some cases within 1-2 years of publication.

Almost half of all studies (46%) used manual vehicle counts, with around one-third (32%) using automatic vehicle counts. Person counts, intercept surveys and household travel surveys were less common (used by 21-24% of all studies), with workplace/school travel surveys used in only 6% of studies. Almost all studies (97%) estimated vehicle trip generation, with a much lower proportion measuring transit (42%), walk (37%) and bicycle (35%) trips. Where transit trips were measured, a distinction between different transit modes was made in relatively few studies (*11; 13-15; 21; 24; 25; 28; 29; 33-37*); transit modes measured by these studies included bus, train/metro and tram/light rail.

The use of person counts, intercept surveys and household travel surveys have experienced a notable increase since around 2008, as has the collection of data relating to transit, walk and bicycle trips, as illustrated by Figure 1. This indicates a much greater emphasis on multi-modal trip generation than past practice which typically focused on vehicle trips only.

Where information was available, Table 3 also indicates the extent to which observed vehicle trip generation rates deviated from corresponding rates published by the Institute of Transportation Engineers (ITE). Considerable variation across the studies is found, ranging from 12% to 415% of the published ITE rates. Much research has highlighted this issue, given the extensive range of site-based contextual variables that can influence vehicle trip generation estimates (*13; 38-43*). However, across all of the studies, the weighted average was remarkably close at 95-104% of the published ITE rates, although this reduced to 79-104% when excluding non-US studies from the sample (see Table 3). In practice, the application of published rates that under or overestimate vehicle trips may lead to a corresponding under or oversupply of roadway capacity for vehicles (*3*).

While a considerable number of trip generation studies have been undertaken, it is far more common for practitioners to adopt (or adjust) an existing published rate in assessing the transport impacts of a proposed land use development (*1*). A summary of key databases which provide published rates are detailed in Table 4. These include the ITE Trip Generation Manual (United States) (*44*), TRICS (United Kingdom and Ireland) (*45*) and the TDB Database (New Zealand and Australia) (*46*). While trip generation databases have also been developed in other jurisdictions, such as South Africa (*47*) and Abu Dhabi (*48*), these tend to be less comprehensive, with reference still made in some sections to the ITE manual. A software program known as *Ver_Bau* has also been developed in Germany for estimating trip generation but only limited information about this program is available in English (*49*). While predominantly used in Germany, Austria and Switzerland, *Ver_Bau* has also been applied in Liechtenstein, France, Luxembourg, the Netherlands, Poland, Czech Republic, Italy and Iceland (*49*). Methods for trip generation are also published in non-English languages in the Netherlands (*50*), Czech Republic (*51*) and Italy (*52*).

Table 4 shows that while the ITE manual contains data for approximately 4,000 sites across 176 land use categories, only around 350 sites (9%) include person trip data and this is not classified by transport mode. In contrast, both TRICS and TDB include multi-modal trip generation data classified by transport mode, with TRICS providing this information for around 1,900 of its 5,200 sites (36%). The TDB Database has considerably less sites in total at 1,100, but around 360 of these (33%) include multi-modal data.

Site-level data is available from the TRICS and TDB databases which allows users to select specific sites that best relate to the proposed development being assessed. A range of site context information is available to support this process, as listed in Table 4. In contrast, the ITE manual does not provide data for individual sites, and while some filtering is possible based on location type, geographical region and development size, no other contextual information is available. As a result, much research has been undertaken in the United States to develop methods that can adjust ITE vehicle trip generation rates to better reflect the local site context, generally based on vehicle mode share and occupancy rate information (*3; 8; 16; 20; 40; 42; 53-56*). These adjustments are particularly relevant for highly urbanised areas with low car use as the ITE rates are almost all based on trip generation studies undertaken in low-density suburban areas with relatively high levels of car use (*20*).

**TABLE 3 Summary of Trip Generation Studies[a], Ordered by Year of Publication**

| Source & Year | Location | Land Use Group | Survey Year/s | No. Sites | Survey Method | | | | | | Transport Mode | | | | Average % of ITE Rate Observed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Manual Vehicle Count | Automatic Vehicle Count | Person Count | Intercept Survey | HH Survey | Work/ School Survey | Vehicle | Transit | Bicycle | Walk | AM Peak | PM Peak | Daily |
| (*38*) 1982 | United States | Residential | 1976 | NA | | | | | • | | • | | | | | | 74% |
| (*57*) 1985 | United States | Various | 1979 | 63 | • | • | | | | | • | | | | | | |
| (*58*) 1985 | United States | Recreational | 1983 | 6 | | | • | • | | | • | • | | • | | | |
| (*59*) 1987 | United States | Lodging | 1985-86 | 7 | • | • | | | | | • | | | | 51% | 56% | 46% |
| (*60*) 1988 | United States | Institutional | NR | 7 | | • | | | | | • | | | | | | 214% |
| (*61*) 1988 | United States | Retail | NR | 2 | | • | | | | | • | | | | | 172% | 120% |
| (*17*) 1989 | United States | Office | 1988 | 23 | | | | • | | • | • | • | • | • | 50% | 48% | |
| (*62*) 1990 | United States | Institutional | NR | 6 | | • | | | | | • | | | | | | 45% |
| (*63*) 1990 | United States | Office | 1989 | 1 | • | | | | | • | • | | | | 82% | 100% | |
| (*64*) 1991 | United States | Various | NR | 6 | | • | | | | | • | | | | 89% | 84% | |
| (*65*) 1991 | Nigeria | Residential | 1987-88 | NA | | | | | • | | • | • | • | • | | | |
| (*66*) 1992 | United States | Various | 1985-90 | 21 | • | | | | | | • | | | | | | |
| (*67*) 1992 | United States | Services | NR | 6 | • | | | | | | • | | | | 77% | 73% | |
| (*68*) 1993 | United States | Retail | 1986-92 | 6 | | • | | | | | • | | | | 29% | 48% | 52% |
| (*69*) 1993 | United States | Services | NR | 30 | • | • | | | | | • | | | | 87% | 79% | 115% |
| (*70*) 1993 | United States | Retail | 1991 | 11 | | • | | | | | • | | | | | | 84% |
| (*71*) 1994 | Canada | Terminal | 1987-92 | 5 | • | • | | | | | • | | | | | | |
| (*72*) 1994 | United States | Retail | NR | 8 | • | • | | | | | • | | | | 83% | 64% | 77% |
| (*73*) 1994 | United States | Institutional | NR | 29 | • | | | | | | • | | | | 75% | 79% | |
| (*74*) 1995 | Mexico | Various | 1994 | 3 | | • | | | | | • | | | | 50% | 59% | |
| (*75*) 1995 | Canada & United States | Residential | 1994 | NA | | | | | • | | • | | | | | | |
| (*76*) 1996 | United States | Residential | 1991-94 | NA | | | | | • | | • | • | • | • | | | |
| (*77*) 1996 | United States | Lodging | NR | 16 | | • | | • | | | • | | | | 128% | 221% | 162% |
| (*78*) 1996 | United States | Institutional | 1993 | 16 | • | • | | | | | • | | | | 193% | 156% | 152% |
| (*79*) 1998 | United States | Retail | 1997 | 27 | • | | | • | | | • | | | | | 65% | |
| (*80*) 1998 | Australia | Residential | 1991-92 | NA | | | | | • | | • | | | | | | |
| (*81*) 1998 | United States | Residential | 1996 | 3 | | • | • | | | | • | • | | | | | |
| (*25*) 1998 | United States | Retail | NR | 6 | | | • | • | | | • | • | • | • | | | 58% |
| (*82*) 1999 | United States | Recreational | NR | 5 | • | • | | | | | • | | | | 12% | 34% | 127% |
| (*83*) 1999 | United States | Recreational | 1996-97 | 8 | | • | | | | | • | | | | | | |
| (*84*) 1999 | United States | Retail | 1997 | 18 | • | | | | | | • | | | | | | |
| (*85*) 2000 | United States | Institutional | 1999 | 12 | | • | | | | | • | | | | 150% | 141% | 154% |
| (*39*) 2001 | Singapore | Retail | NR | 8 | • | | | | | | • | | | | | | |
| (*86*) 2001 | United States | Retail | NR | 28 | • | | | • | | | • | | | | 72% | 58% | |
| (*87*) 2001 | Greece | Institutional | NR | NR | | | | | | • | • | • | • | • | | | 115% |
| (*88*) 2001 | United States | Recreational | 2000 | 3 | | • | | | | | • | | | | | | |
| (*89*) 2002 | United States | Various | NR | 46 | • | | | | | | • | | | | | | |

| Source & Year | Location | Land Use Group | Survey Year/s | No. Sites | Survey Method | | | | | | Transport Mode | | | | Average % of ITE Rate Observed | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Manual Vehicle Count | Automatic Vehicle Count | Person Count | Intercept Survey | HH Survey | Work/ School Survey | Vehicle | Transit | Bicycle | Walk | AM Peak | PM Peak | Daily |
| (*22*) 2003 | United States | Retail | NR | 10 | | • | | • | | | • | • | • | • | 138% | 82% | 85% |
| (*90*) 2003 | United States | Medical | NR | 3 | • | • | | | | | • | | | | 289% | 217% | 275% |
| (*91*) 2006 | Mexico | Residential | 1994 | NA | | | | | • | | • | • | • | • | | | |
| (*92*) 2006 | United States | Residential | NR | 9 | • | | | | • | | • | | | | | | |
| (*93*) 2006 | United States | Residential | NR | 9 | • | | | | • | | • | | | | | | 102% |
| (*94*) 2006 | United States | Retail | 2003 | 5 | • | | | | | | • | | | | | 141% | |
| (*95*) 2007 | United States | Retail | NR | 6 | • | | | | | | • | | | | | | |
| (*96*) 2007 | United States | Residential | 2005 | 1 | • | | | | | | • | | | | 90% | 127% | |
| (*97*) 2008 | Saudi Arabia | Services | 1998-00 | 20 | • | | | | | | • | | | | | 58% | |
| (*41*) 2008 | United States | Residential | 2007 | 17 | | • | | | | | • | | | | 51% | 52% | 56% |
| (*98*) 2008 | Ireland | Various | 2004-07 | 33 | • | | | | | | • | | | | | | |
| (*27*) 2009 | United States | Various | NR | 26 | | | | • | | | • | • | • | • | 52% | 61% | |
| (*33*) 2009 | United Kingdom | Various | 2005/08 | 4 | • | | • | | | | • | • | • | • | | | |
| (*99*) 2009 | United States | Services | 2008 | 22 | • | | | | | | • | | | | | 85% | |
| (*100*) 2009 | United States | Retail | 2007 | 32 | • | | | | | | • | | | | 93% | 117% | 115% |
| (*101*) 2009 | Saudi Arabia | Institutional | 2006 | 29 | • | | | | | | • | | | | | | |
| (*102*) 2010 | Canada | Institutional | 2009-10 | 20 | • | | | | | • | • | • | • | • | | | |
| (*103*) 2010 | United States | Recreational | 2006-09 | 17 | • | | | | | | • | | | | 117% | 123% | |
| (*104*) 2010 | Indonesia | Various | NR | NA | | | | | • | | | • | | | | | |
| (*105*) 2011 | United States | Various | 1991-01 | 239 | | | | | • | | • | • | | • | | | |
| (*106*) 2011 | United States | Services | 2007 | 13 | • | | | | | | • | | | | 46% | | |
| (*107*) 2011 | United States | Residential | NR | 4 | • | • | | | | | • | | | | 415% | 282% | |
| (*18*) 2011 | Taiwan | Various | 2007 | NA | | | | | | • | • | • | • | • | | | |
| (*11*) 2011 | New Zealand | Various | 2010 | 7 | | | • | • | | | • | • | • | • | | | |
| (*108*) 2012 | United States | Various | 2008-09 | NR | • | | | | | | • | | | | 83% | 116% | |
| (*53*) 2012 | United States | Various | 2006 | NA | | | | | • | | • | • | • | • | | | |
| (*13*) 2012 | United States | Various | 2011 | 78 | • | | • | • | | | • | • | • | • | | 64% | |
| (*109*) 2012 | United States | Retail | 2006 | 10 | • | • | | | | | • | | | | 125% | 79% | 90% |
| (*23*) 2012 | United States | Retail | NR | 54 | | • | • | | | | • | • | • | • | | 122% | 107% |
| (*110*) 2012 | United States | Various | 2009 | 4 | | • | | • | | | • | • | | | 134% | 55% | 58% |
| (*111*) 2012 | United States | Services | 2009-10 | 8 | • | | | | | | • | | | | 240% | 160% | |
| (*54*) 2012 | United States | Various | NR | 22 | | • | | • | | | • | | | | 63% | 71% | 95% |
| (*24*) 2013 | United States | Various | 2010-12 | 16 | | • | | | • | | • | • | • | • | 72% | 64% | 56% |
| (*20*) 2013 | United States | Various | 2008/11 | 14 | • | | • | | • | | • | • | • | • | 49% | 83% | |
| (*15*) 2013 | United States | Various | 2007-08 | NA | | | | | • | | • | • | • | • | | | |
| (*112*) 2013 | South Korea | Office | 2009 | 28 | • | | | | | | • | | | | 26% | | |
| (*28*) 2013 | United States | Various | 2012 | 30 | | | • | • | | | • | • | • | • | 44% | 42% | |
| (*34*) 2014 | United Kingdom | Residential | 2013 | 8 | | | • | | • | | • | • | • | • | | | |

| **Source & Year** | **Location** | **Land Use Group** | **Survey Year/s** | **No. Sites** | **Survey Method** | | | | | | **Transport Mode** | | | | **Average % of ITE Rate Observed** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Manual Vehicle Count | Automatic Vehicle Count | Person Count | Intercept Survey | HH Survey | Work/ School Survey | Vehicle | Transit | Bicycle | Walk | AM Peak | PM Peak | Daily |
| (*113*) 2014 | United States | Residential | 2007-08 | NA | | | | | • | | • | • | • | • | | | |
| (*16*) 2015 | United States | Various | 2001-11 | 195 | | | | | • | | • | • | • | • | | | |
| (*21*) 2015 | United States | Various | 2013-15 | 61 | • | | • | • | | | • | • | • | • | 38% | 37% | |
| (*26*) 2015 | Australia | Residential | 2014 | 8 | | | • | | | | • | • | • | • | 49% | | |
| (*35*) 2015 | United States | Various | 2013-14 | 16 | | | • | • | | | • | • | • | • | | | |
| (*114*) 2015 | United States | Various | 2009 | NA | | | | | • | | • | | | | | | 65% |
| (*115*) 2015 | South Africa | Various | 2007-13 | NA | | | | | • | | | • | | | | | |
| (*3*) 2015 | United States | Various | 2006-12 | 65 | | • | • | • | | | • | | | | 65% | 58% | |
| (*116*) 2015 | United States | Various | 2004-12 | 412 | | | | | • | | • | • | • | • | | | |
| (*117*) 2015 | United States | Various | NR | 78 | | • | | | | | • | | | | | | |
| (*118*) 2016 | Australia | Institutional | 2013 | 15 | • | | • | • | | | • | • | • | • | | | |
| (*19*) 2016 | Venezuela | Institutional | 2011-15 | 32 | • | | • | | | • | • | • | • | • | | | |
| (*119*) 2017 | Palestine | Various | NR | 136 | • | | | | | | • | | | | 180% | 190% | |
| (*29*) 2017 | United States | Various | 2015 | 5 | | | • | • | | | • | • | • | • | | | 47% |
| (*14*) 2017 | Australia | Residential | 2009-10 | NA | | | | | • | | | • | | | | | |
| (*36*) 2017 | United States | Various | 2015 | 30 | • | | • | • | | | • | • | • | • | 63% | 58% | |
| (*120*) 2018 | Jordan | Retail | NR | 28 | • | | • | | | | • | • | • | • | | 76% | |
| (*37*) 2018 | United States | Various | 2017 | 1 | | | • | • | | | • | • | • | • | | | 59% |
| (*43*) 2018 | United States | Residential | 2010-12 | NA | | | | | • | | • | • | • | • | | | |
| (*121*) 2018 | United States | Residential | 2004-12 | NA | | | | | • | | • | | | | | | 37% |
| Total | | | | | 44 | 30 | 20 | 20 | 23 | 6 | 92 | 40 | 33 | 35 | | | |
| % of studies | | | | | 46% | 32% | 21% | 21% | 24% | 6% | 97% | 42% | 35% | 37% | | | |
| Weighted average (weighted by no. sites) | | | | | | | | | | | | | | | 95% | 95% | 104% |
| Weighted average (weighted by no. sites), excluding non-US studies | | | | | | | | | | | | | | | 79% | 80% | 104% |

[a] Includes original source studies only; where several publications reported findings using the same dataset, only the original or main study was included.
Note: HH survey = household travel survey, work/school survey = workplace/school travel survey, ITE = Institute of Transportation Engineers, NR = not reported, NA = not applicable.
*Source:* Author’s synthesis of the literature.

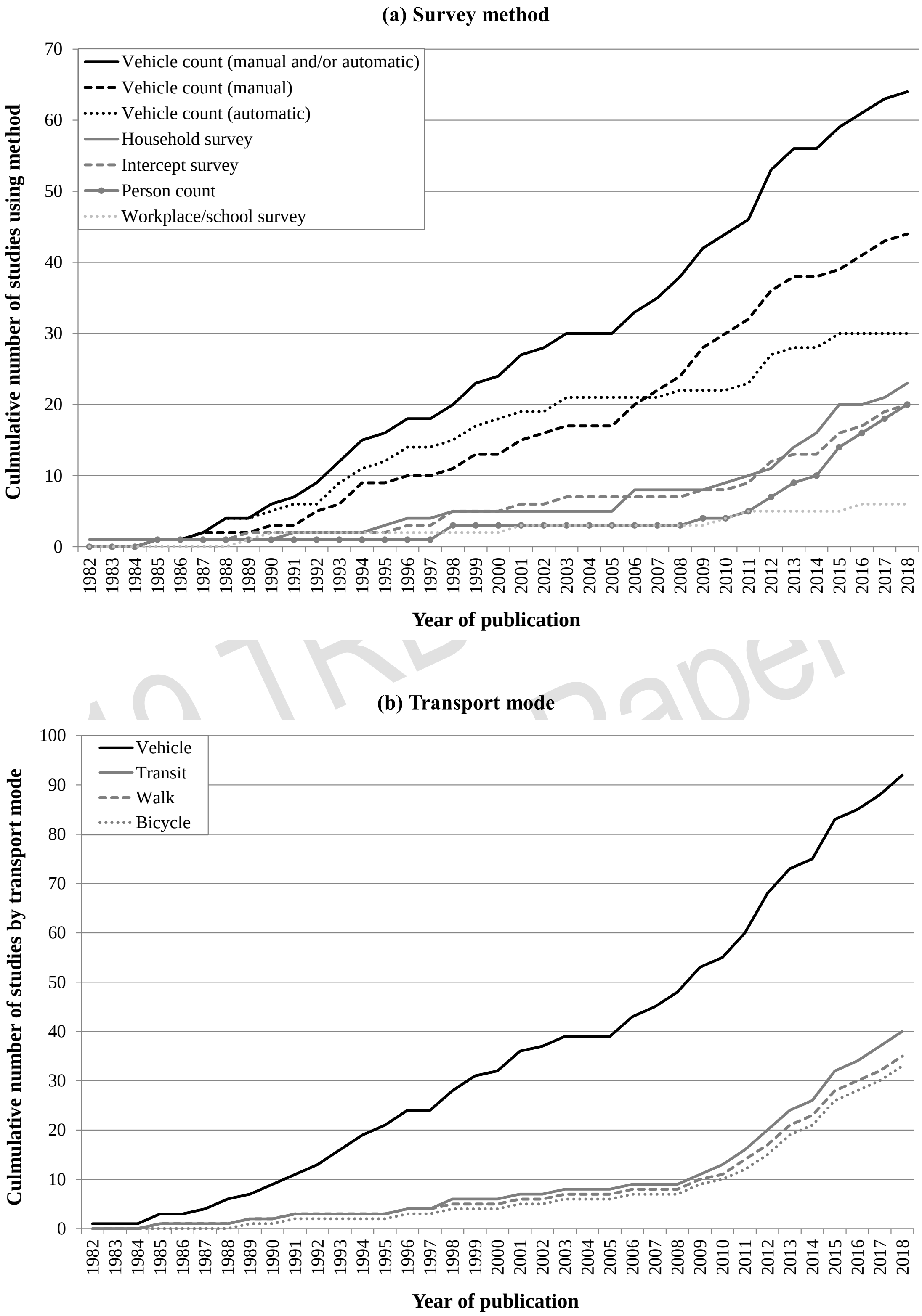


**FIGURE 1 Cumulative number of trip generation studies by (a) survey method and (b) transport mode.**

**TABLE 4 Comparison of Key Trip Generation Databases**

| Characteristic | ITE Trip Generation Manual 10th Edition (*44*) | TRICS Version 7.5.1 (*45*) | TDB Database 2018 Version[a] (*46*) |
|---|---|---|---|
| First published | 1976 | 1989 | 2002 |
| Latest release | 2017 | 2018 | 2018 |
| Format | Document and online tool | Online software | Spreadsheet |
| Coverage | United States & Canada | United Kingdom & Ireland | New Zealand & Australia |
| No. land use categories | 176 | 110 | 77 |
| No. surveyed sites | 4,000 (approx.)[b] | 5,229 | 1,103 |
| No. multi-modal surveyed sites | 350 (approx.)[c] (9% of all sites) | 1,907 (36% of all sites) | 361 (33% of all sites) |
| Transport modes | • Vehicle trips<br>• Person trips | • Car (by driver and passenger)<br>• Goods vehicle (light and heavy)<br>• Public transport (by bus, tram, rail, coach, ferry)<br>• Taxi<br>• Walk<br>• Cycle<br>• Motorcycle | • Car (by driver and passenger)<br>• Goods vehicle (by driver and passenger)<br>• Public transport<br>• Walk<br>• Cycle<br>• Motorcycle<br>• Other |
| Site-level data | No | Yes | Yes |
| Site context information | • Location type (e.g. urban/suburban, rural)<br>• Geographical region (e.g. midwest, southwest)[d]<br>• Development size (e.g. floor area, dwellings)[d] | • Site address and coordinates (latitude, longitude)<br>• Location type (e.g. town centre, suburban area)<br>• Population (within 500m, 1mi, 5mi)<br>• Car ownership (within 5mi)<br>• Census data for local area (e.g. people employed)<br>• Site topography (hilly or flat)<br>• Distance to local facilities (e.g. supermarket)<br>• Public transport accessibility level (PTAL)<br>• Public transport provision (no. services by mode)<br>• Design features for non-car modes (e.g. footpaths)<br>• Development size (e.g. floor area, dwellings)<br>• Site opening hours<br>• Parking supply on-site (by user type) incl. charges<br>• Parking supply on-street, incl. restrictions/charges<br>• Travel (TDM) plan, incl. status of initiatives | • Site address and coordinates (latitude, longitude)<br>• Location type (e.g. inner suburban, outer suburban)<br>• Population (within 1km, 5km; total for urban area)<br>• Frontage road traffic volume<br>• Pedestrian activity ('nil' to 'very high')<br>• Public transport accessibility ('nil' to 'very high')<br>• Development size (e.g. floor area, dwellings)<br>• Parking supply on-site<br>• Parking supply on-street |

[a] Incorporates all trip generation data from the 2002 Roads and Traffic Authority (RTA) 'Guide to Traffic Generating Developments' in New South Wales, Australia.
[b] Estimate based on maximum no. of sites quoted for each land use category in database; note that data collected before 1980 is not included in latest (10th) edition of the database.
[c] Represents person trip surveys only; estimate based on maximum no. of person trip survey sites quoted for each land use category in database.
[d] This information is available only via the online tool: *ITETripGen*.
Note: ITE = Institute of Transportation Engineers, TRICS = Trip Rate Information Computer System, TDB = Trips Database Bureau, TDM = Travel Demand Management.
*Source:* Author's synthesis of the literature.

## Key issues in estimating and applying multi-modal trip generation rates

Table 5 summarises key issues associated with estimating and applying multi-modal trip generation rates. While issues associated with trip generation more generally have been noted by the literature (*8; 122*), five main issues were identified with specific relevance to multi-modal trip generation. Opportunities to address these issues are discussed as part of the next section.

The first key issue relates to the lack of sufficient multi-modal trip generation data. This is particularly relevant in the United States where the ITE manual still contains relatively little person trip data (9% of all sites). Efforts are underway to integrate the Australian and New Zealand (TDB) data within the TRICS (United Kingdom and Ireland) database, yet a truly joint international database is still lacking (*123*). At a more local level, consultants and others are not necessarily incentivised to share their own collected data, which only further confines the availability of trip generation data (*122; 124*).

The second key issue is that multi-modal trip generation studies tend to be more complex and resource intensive than vehicle only studies. The need to interact with site users can increase survey costs considerably, as can the use of multiple survey methods (*11; 125*). For example, a site with multiple access points would typically require an intercept survey and person count at each doorway, in addition to what would usually be a vehicle count only at each vehicle entrance/exit point.

A continued focus on vehicle trips in Transport Impact Assessments (TIAs) is the third key issue. Despite best practice suggesting otherwise (*2; 32*), there still remains an emphasis in many jurisdictions on assessing traffic, rather than transport impacts. A key observation is that while person trip data has been collected throughout the United States, this is in many cases only used to derive a more accurate estimate of vehicle trip generation, rather than to plan effectively for all modes (*6*).

The last two issues both relate to sample size. The presence of many different site-based factors that can affect multi-modal trip generation, coupled in some cases with relatively small numbers of non-vehicle trips, means that a sufficiently large number of sites surveyed over longer than usual timeframes may be needed to both understand the influence of site context and to estimate multi-modal trip generation with reasonable accuracy (*3; 36*).

**TABLE 5 Key Issues in Estimating and Applying Multi-Modal Trip Generation Rates**

| Key Issue | Supporting Comments and Evidence |
|---|---|
| 1. Lack of sufficient multi-modal trip generation data | • Past focus has primarily been on vehicle trip generation (see Figure 1)<br>• While some multi-modal data is now available in databases, this is still limited (see Table 4)<br>• Limited inclination by the private sector exists to share trip generation data (*122; 124*) |
| 2. Data collection tends to be resource intensive and complex | • Collection of multi-modal trip generation data generally cannot be done through observation alone; there is often the need for intercept surveys to seek input from site users (*11; 28; 35*)<br>• Getting permission from property managers to collect data can be difficult to obtain (*27*)<br>• Collecting multi-modal data often requires multiple survey methods, increasing cost (*125*) |
| 3. Primary focus still remains on vehicle trips in many instances | • While person trip data is becoming more available, much of this is used only for the purpose of developing more accurate estimates of vehicle trip generation, at least in the United States (*6*)<br>• Despite the (limited) availability of multi-modal data, most practice still tends to focus only on vehicle trips in assessing the transport impacts of a proposed development (*32; 118*) |
| 4. Extensive range of site contextual factors that exist can affect estimates | • Multi-modal trip generation is influenced by various site-based factors that are not always collected, such as socio-demographics, parking provision and urban design aspects (*123; 126*)<br>• Unobserved factors (e.g. cycling culture) can lead to much variation in multi-modal trip generation rates even among sites of the same land use in the same types of location (*93*)<br>• Understanding the influence of many different site contextual factors on multi-modal trip generation can require a relatively large sample of sites (*3; 125*) |
| 5. Relatively small sample sizes may be associated with non-vehicle modes | • Where the sample size of trips by non-vehicle modes is small, longer survey periods are generally needed to estimate multi-modal trip generation with reasonable accuracy (*36*)<br>• Household travel survey data may not provide a sufficient sample of transit trips (*14*) |

*Source:* Author’s synthesis of the literature

## Knowledge gaps and opportunities for future research

Based on the issues highlighted earlier, along with research needs identified by the literature, Table 6 details key knowledge gaps and opportunities for future research in multi-modal trip generation.

While intercountry comparisons of vehicle trip generation rates have been undertaken (*123*), no research has compared multi-modal trip generation rates across jurisdictions. Doing so would help to establish the potential for data sharing, transferability of trip generation rates and ultimately the development of an international trip generation database (*13; 122*). This would also help in part to address the issue identified earlier (Table 5) related to the lack of sufficient multi-modal trip generation data.

Opportunity also exists to move towards greater standardisation in the way that multi-modal trip generation data is collected, potentially building on the TRICS multi-modal methodology (*12*). As part of this, consideration should be given to exploring the use of alternative data collection methods, particularly the use of technologies that do not necessarily require input from site users (*8; 127*). Examples include Bluetooth sensors, Wi-Fi sensors, crowd-sourced traveller data (e.g. from smartphones), and data potentially collected by connected and automated vehicles. Improved standardisation in data collection, combined with the use of technologies, could potentially help to lessen the extent of resource intensiveness and complexity in collecting multi-modal trip generation data, but also shift the focus away from vehicle trips only so as to better inform planning for all modes of transport (see Table 5).

Largely in part due to the lack of sufficient data, limited research has explored factors affecting multi-modal trip generation (*11; 13; 16*). However, an excellent opportunity exists to draw on the extensive sample of sites in the TRICS and TDB databases to perform such an analysis. Doing so would help to address the issues identified earlier (Table 5) associated with understanding site-based factors that can affect multi-modal trip generation, coupled with the relatively small sample size of non-vehicle trips.

Finally, and while not identified earlier in Table 5 as a key issue, much scope exists for undertaking post development reviews of transport assessments to assess the accuracy of the process, given the importance of assumptions regarding trip generation and mode split (*1; 98*).

**TABLE 6 Knowledge Gaps and Opportunities for Future Research in Multi-Modal Trip Generation**

| Knowledge Gap | Opportunities for Future Research |
|---|---|
| 1. There are no published cross-jurisdictional comparisons of multi-modal trip generation data | Analyse differences in multi-modal trip generation rates across jurisdictions, with consideration of elements required to support the development of an international trip generation database (*13; 122; 123*) |
| 2. Little standardisation exists in methods used for collecting multi-modal trip generation data | Develop a standardised approach to multi-modal data collection for other (non-UK) jurisdictions, building on the TRICS methodology (*11; 12*) |
| 3. There has been limited exploration of alternative multi-modal data collection methods | Review and test available technologies to support multi-modal data collection, e.g. bluetooth, smartphone tracking (*8; 127*) |
| 4. Limited research has explored factors affecting multi-modal trip generation | Use TRICS and TDB data, along with collecting multi-modal trip generation data at more sites, to assess the influence of site-based factors but also other factors such as hourly and seasonal variations (*11; 28*) |
| 5. There is little understanding of the accuracy of multi-modal trip generation estimates in TIAs | Conduct before and after comparisons of trip generation and mode split estimates at selected sites to verify accuracy of the TIA process (*1; 63; 98*) |

## DISCUSSION AND CONCLUSION

The aim of this paper was to provide an international review of multi-modal trip generation associated with land use developments. The review found that while multi-modal trip generation studies have been relatively scant, they have been subject to greater attention in the last 10 years. A range of issues were identified with estimating and applying multi-modal trip generation rates, not least is the lack of sufficient data and higher complexity in data collection compared to vehicle only trip generation studies. Current knowledge gaps highlight opportunities to move towards greater international coordination and sharing of multi-modal trip generation data, along with exploring the potential for technologies to assist with data collection requirements. Based on the insights gained from the review, this section of the paper suggests four key directions to guide future practice and policy in the field of multi-modal trip generation.

First, a fundamental change in paradigm is needed that acknowledges the need to *consistently* account for multi-modal trip generation, both within and across jurisdictions. This requires a shift away from historical practice, which has typically focused on vehicles only, towards the detailed consideration of *all* transport modes. By its very nature, trip generation is about trips made by *people*, not vehicles (*128*). While multi-modal trip generation studies are generally more resource intensive, this needs to be accepted by the transport community as the 'norm' and built into planning and budget estimates where applicable. There are of course land use developments where vehicle trips make up the large majority of total trips, but without at least assessing their impact on other potential modes, the focus remains on vehicles at the expense of investment directed towards other forms of transport (*7; 32*). Many of the studies reviewed in this research omitted the term 'vehicle' when referring to trip generation, despite being focused solely on vehicle trip generation. While practice is slowly changing in this regard, greater emphasis is needed to ensure all modes of transport are adequately considered in planning for new land use developments (*32*). In addition, emerging transport technologies and related services (e.g. paratransit, electric scooters, bike share systems, automated vehicles) will also need to be considered in the context of future multi-modal trip generation trip estimates and the opportunities these can provide for new forms of data collection.

Second, much opportunity exists to develop an international multi-modal trip generation database. Efforts are currently underway to house Australian and New Zealand data within the TRICS (United Kingdom and Ireland) database, but this could be extended further with data from the United States and elsewhere. Doing so would help to increase the availability of multi-modal trip generation data and would also reduce the reliance on vehicle only rates, particularly in the United States. There are of course a number of practicalities around establishing such a database, such as data management and governance arrangements, but the integration of Australian and New Zealand data into TRICS should provide a basis from which future efforts can proceed. While trip generation rates could be provided separately for each participating jurisdiction, they could also be combined where differences are not significant to provide a larger sample of sites. Indeed, previous comparisons of trip rates from New Zealand and the United Kingdom have shown similarities in many cases (*123*). To ensure currency of the database, some mechanism or incentive would need to be put in place to encourage consultants and others to regularly submit their trip generation data (*129*), such as subsidised database membership or guaranteed data collection work. Regardless, the incentive would need to be large enough for the number of sites in the database to readily increase over time.

Third, a universal shift towards the use of multi-modal trip generation rates in TIAs needs to occur. Without the means to *quantify* trip generation by each mode, the ability to plan effectively for each mode is severely limited. TIAs all too often conclude with a statement indicating that 'the development is not expected to have any significant impact on the operation of the surrounding road network', even when non-vehicle trips may account for the majority of total trips. This practice needs to change to give a more appropriate level of consideration to all modes of transport. Fortunately, practice is changing in this regard (*2; 5; 7*), yet the field has a long way to go as applications are still patchy at best.

Fourth, given the high levels of variability in trip generation rates, even for identical land uses in similar contexts (*93*), greater use of sensitivity testing and scenario planning in assessing the transport impacts of new land use developments is needed (*1*). Infinite variations over innumerable sites means that no single estimate of trip generation is likely to ever be correct. This is particularly relevant in the context of multi-modal trip generation where the demand for each mode is influenced by many different factors. A move towards using lower and upper estimates (*49*), potentially based on 95% confidence intervals, could be a option while accepting that uncertainty and error is inherent in the process (*6; 93*).

While considerable effort was made to source all relevant literature for this review, there are likely to be unpublished reports from practitioners that have not been captured by this paper, along with relevant literature published in languages other than English. However, strengths of this literature review include a number of syntheses on different aspects of multi-modal trip generation, previously not available. These syntheses have helped to understand past and current trends in multi-modal trip generation, thereby informing the development of recommendations to guide future policy and practice in this field.

In closing, it is particularly important that all transport modes are included in the trip generation process. Doing so provides a much better ability to plan effectively for walking, cycling and transit trips, not just travel by private vehicles. In turn, this will contribute to improved sustainability and liveability outcomes from new land use developments over the longer term.

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## AUTHOR CONTRIBUTION STATEMENT

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

## REFERENCES

[1] De Gruyter, C., and P. Wills. Transport Impact Assessment. *Traffic Engineering and Management, 7th Edition*, Monash Institute of Transport Studies, Monash University, Clayton, Victoria, Australia, 2017.
[2] Cooley, K., C. De Gruyter, and A. Delbosc. A best practice evaluation of traffic impact assessment guidelines in Australia and New Zealand. Presented at 38th Australasian Transport Research Forum (ATRF), Melbourne, Australia, 2016.
[3] Schneider, R. J., K. Shafizadeh, and S. Handy. Method to adjust Institute of Transportation Engineers vehicle trip-generation estimates in smart-growth areas. *The Journal of Transport and Land Use,* Vol. 8, No. 1, 2015, pp. 69-83.
[4] Ridgway, M. D., and S. Tabibnia. Transportation impact studies - Analysis of alternative transportation modes. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Las Vegas, Nevada, United States, 1999.
[5] Hardy, D., E. Graye, and C. Van Nostrand. Facilitating smart growth with context-sensitive transportation review of site development. Presented at 97th Transportation Research Board (TRB) Annual Meeting, Washington, D.C., United States, 2018.
[6] Clifton, K. J., and K. M. Currans. A sustainable multimodal planning framework for transportation impact analysis. Presented at 96th Transportation Research Board (TRB) Annual Meeting, Washington, D.C., United States, 2017.
[7] Zimbabwe, S., M. Parker, J. Henson, and B. White. Development review in the District of Columbia: Transitioning from a traditional traffic impact study to comprehensive multi-modal transportation review. Presented at 92nd Transportation Research Board (TRB) Annual Meeting, Washington, D.C., United States, 2013.
[8] Currans, K. M. Issues in trip generation methods for transportation impact estimation of land use developments: A review and discussion of the state-of-the-art approaches. *Journal of Planning Literature,* Vol. 32, No. 4, 2017, pp. 335-345.
[9] Westrom, R., S. Dock, J. Henson, M. Watten, A. Bakhru, M. Ridgway, J. Ziebarth, R. Prabhakar, N. Ferdous, G. R. Kilim, and R. Paradkar. Multimodal trip generation model to assess travel impacts of urban developments in the District of Columbia. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2668, 2017, pp. 29-37.
[10] Van Wee, B., and D. Banister. How to write a literature review paper? *Transport Reviews,* Vol. 36, No. 2, 2016, pp. 278-288.
[11] Pike, L. Generation of walking, cycling and public transport trips: pilot study. NZ Transport Agency, Wellington, New Zealand, 2011.
[12] TRICS. TRICS multi-modal methodology 2014. TRICS, London, United Kingdom, 2014.
[13] Clifton, K. J., K. M. Currans, and C. D. Muhs. Contextual influences on trip generation. Oregon Transportation Research and Education Consortium (ORTEC), Portland, Oregon, United States, 2012.
[14] Kim, J., A. Delbosc, and C. De Gruyter. Estimating residential public transport trip generation rates. Presented at Australian Institute of Traffic Planning and Management (AITPM) National Conference,

Melbourne, Australia, 2017.
[15] Faghri, A., and M. Venigalla. Measuring Travel Behaviour and Transit Trip Generation Characteristics of Transit-Oriented Developments. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2397, 2013, pp. 72-79.
[16] Currans, K. M., and K. J. Clifton. Using household travel surveys to adjust ITE trip generation rates. *The Journal of Transport and Land Use,* Vol. 8, No. 1, 2015, pp. 85-119.
[17] Schwartz, W. L., and R. A. Easler. Developing urban office trip generation rates and traffic mitigation measures in Cambridge, Massachusetts. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, San Diego, California, United States, 1989.
[18] Lin, J.-J., and T.-P. Yu. Built environment effects on leisure travel for children: Trip generation and travel mode. *Transport Policy,* Vol. 18, No. 1, 2011, pp. 246-258.
[19] Quintero, A., M. Diaz, and E. Moreno. Trip generation by transportation mode of private school, semi-private and public. Case study in Merida-Venezuela. *Transportation Research Procedia,* Vol. 18, 2016, pp. 73-79.
[20] Daisa, J. M., M. Schmitt, P. Reinhofer, K. Hooper, B. Bochner, and L. Schwartz. Trip generation rates for transportation impact analyses of infill development. Transportation Research Board, Washington, D.C., United States, 2013.
[21] DDOT. Trip generation and data analysis study. District Department of Transportation, Washington, D.C., United States, 2015.
[22] Brehmer, C. L., and M. A. Butorac. Trip generation characteristics of discount supermarkets. *ITE Journal,* Vol. 73, No. 11, 2003, pp. 38-42.
[23] Guttenplan, M., H. Munroe, A. Piszczatoski, T. Smith, and G. Sokolow. Trip generation characteristics of small box retail stores, major single retailer distribution centers, and free-standing discount superstores. *ITE Journal,* Vol. 82, No. 6, 2012, pp. 36-40.
[24] Arlington County Commuter Services. Residential Building Transportation Performance Monitoring Study. Arlington, Virginia, United States, 2013.
[25] Steiner, R. Trip generation and parking requirements in traditional shopping districts. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1617, 1998, pp. 28-37.
[26] De Gruyter, C., G. Rose, and G. Currie. Understanding Travel Plan Effectiveness for New Residential Developments. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2537, 2015, pp. 126-136.
[27] Daisa, J. M., and T. Parker. Trip generation rates for urban infill land uses in California. *ITE Journal,* Vol. 79, No. 6, 2009, pp. 30-32,37-39.
[28] Schneider, R. J., K. Shafizadeh, B. R. Sperry, and S. Handy. Methodology to gather multimodal trip generation data in smart-growth areas. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2354, 2013, pp. 68-85.
[29] Ewing, R., G. Tian, T. Lyons, and K. Terzano. Trip and parking generation at transit-oriented developments: Five US case studies. *Landscape and Urban Planning,* Vol. 160, 2017, pp. 69-78.
[30] Pahl-Weber, E., and D. Henckel. The planning system and planning terms in Germany: A glossary. Academy for Spatial Research and Planning, Hanover, Germany, 2008.
[31] MAX. WP D Working Stage Analysis 1: Comparison of integration of sustainable transport, mobility management and land use planning in WP D partner countries. Sixth Framework Programme, European Commission, Brussels, Belgium, 2007.
[32] DeRobertis, M., J. Eells, J. Kott, and R. W. Lee. Changing the paradigm of traffic impact studies: How typical traffic studies inhibit sustainable transportation. *ITE Journal,* Vol. 84, No. 5, 2014, pp. 30-35.
[33] JMP. Effect of travel plans. JMP Consultants Limited, London, United Kingdom, 2009.
[34] WSP. Does car ownership increase car use? A study of the use of car parking within residential developments in London. Commissioned by the Berkeley Group, United Kingdom, 2014.
[35] Dock, S., L. Cohen, J. D. Rogers, J. Henson, R. Weinberger, J. Schrieber, and K. Ricks. Methodology to gather multimodal urban trip generation data. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2500, 2015, pp. 48-58.
[36] TTI. Caltrans project P359, Trip generation rates for transportation impact analyses of smart growth land use projects: Final report. Texas A&M Transportation Institute, College Station, Texas, United

States, 2017.
[37] Ewing, R., G. Tian, K. Park, P. Stinger, and J. Southgate. Trip and parking generation study of Orenco Station TOD, Portland region. Presented at 97th Transportation Research Board (TRB) Annual Meeting, Washington, D.C., United States, 2018.
[38] Reid, F. A. Critique of ITE trip generation rates and an alternative basis for estimating new area traffic. *Transportation Research Record*, No. 874, 1982, pp. 1-5.
[39] Fan, H. S. L., and Y. W. Tan. Trip generation of retail developments in Singapore. *ITE Journal,* Vol. 71, No. 9, 2001, pp. 30-34.
[40] Gard, J. Innovative intermodal solutions for urban transportation paper award: Quantifying transit-oriented development's ability to change travel behavior. *ITE Journal,* Vol. 77, No. 11, 2007, pp. 42-46.
[41] Cervero, R., and G. B. Arrington. Vehicle trip reduction impacts of transit-oriented housing. *Journal of Public Transportation,* Vol. 11, No. 3, 2008, pp. 1-17.
[42] Clifton, K. J., K. M. Currans, and C. D. Muhs. Adjusting ITE's trip generation handbook for urban context. *The Journal of Transport and Land Use,* Vol. 8, No. 1, 2015, pp. 5-29.
[43] Howell, A., K. M. Currans, G. Norton, and K. J. Clifton. Transportation impacts of affordable housing: Informing development review with travel behavior analysis. *The Journal of Transport and Land Use,* Vol. 11, No. 1, 2018, pp. 103-118.
[44] Institute of Transportation Engineers. Trip Generation Manual, 10th Edition, Volume 2: Data. Institute of Transportation Engineers, Washington D.C., United States, 2017.
[45] TRICS. Trip Rate Information Computer System (TRICS) Version 7.5.1. TRICS Consortium Limited, United Kingdom, 2018.
[46] TDB. Trips Database Bureau (TDB) Database. Christchurch, New Zealand, 2018.
[47] COTO. South African Trip Data Manual. Committee of Transport Officials, South Africa, 2013.
[48] Department of Transport. Trip Generation and Parking Rates Manual. Department of Transport, Abu Dhabi, United Arab Emirates, 2012.
[49] Bosserhoff, D. Program Ver_Bau: Estimation of traffic volumes generated by land use planning. Büro Bosserhoff, Gustavsburg, Germany, 2018.
[50] CROW. Kencijfers parkeren en verkeersgeneratie [Parking figures and traffic generation]. CROW, Ede, The Netherlands, 2012.
[51] Martolos, J., V. Šindlerová, L. Bartoš, and J. Mužík. Metody prognózy intenzit generované dopravy [Methods of forecasting the intensity of traffic generated]. EDIP, Plzeň, Czech Republic, 2013.
[52] Quaglia, L., and A. Novarin. Macropoli attrattori di traffico [Macropoli traffic attractors]. EGAF, Traffic and Transport Techniques - AIIT, Forlì, Italy, 2006.
[53] Clifton, K. J., K. M. Currans, A. C. Cutter, and R. Schneider. Household travel survey in context-based approach for adjusting ITE trip generation rates in urban contexts. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2307, 2012, pp. 108-119.
[54] Shafizadeh, K., R. Lee, D. Niemeier, T. Parker, and S. Handy. Evaluation of operation and accuracy of available smart growth trip generation methodologies for use in California. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2307, 2012, pp. 120-131.
[55] Gulden, J., J. P. Goates, and R. Ewing. Mixed-use development trip generation model. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2344, 2013, pp. 98-106.
[56] Walters, J., B. Bochner, and R. Ewing. Getting trip generation right: Eliminating the bias against mixed use development. American Planning Association (APA), Washington, D.C., United States, 2013.
[57] Arnold, E. D. Trip generation at special sites. *ITE Journal,* Vol. 55, No. 3, 1985, pp. 15-19.
[58] Baumgaertner, W. E. Movie theater trip generation rates. *ITE Journal,* Vol. 55, No. 6, 1985, pp. 44-49.
[59] Woods, S. M. Trip generation rates for budget-style motels. *ITE Journal,* Vol. 57, No. 12, 1987, pp. 23-25.
[60] Hazarvartian, K. E. Trip generation characteristics of air force bases. *ITE Journal,* Vol. 58, No. 10, 1988, pp. 17-20.
[61] Hensen, R. J. Trip generation rates for different types of grocery stores. *ITE Journal,* Vol. 58, No. 10, 1988, pp. 21-22.
[62] Hitchens, P. W. Trip generation of day care centers. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Orlando, Florida, United States, 1990.

[63] Murphy, R. P. Traffic impact study assumptions: A before and after analysis. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Orlando, Florida, United States, 1990.
[64] Fehribach, W. J., and J. D. Fricker. Processing trip generation data to avoid overestimating impacts. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Milwaukee, Wisconsin, United States, 1991.
[65] Osula, D. O. A. Development of trip generation models for land uses in Nigeria. *ITE Journal,* Vol. 61, No. 1, 1991, pp. 28-31.
[66] Ackeret, K. W., and R. C. Hosea. Trip generation rates for Las Vegas area hotel-casinos. *ITE Journal,* Vol. 62, No. 5, 1992, pp. 33-37.
[67] Datta, T. K., and P. A. Guzek. Trip generation characteristics at gasoline service stations. *ITE Journal,* Vol. 62, No. 7, 1992, pp. 41-43.
[68] Guckert, W. Trip generation comparisons of club warehouse stores. *ITE Journal,* Vol. 64, No. 4, 1993, pp. 26-28.
[69] Kawamura, J. H. Service station trip generation. *ITE Journal,* Vol. 63, No. 3, 1993, pp. 23-28.
[70] Schumacher, S. Trip generation: One developer's experience. *ITE Journal,* Vol. 63, No. 10, 1993, pp. 35-43.
[71] Kok, E. A. G., J. Morrall, and Z. Toth. Trip generation rates for light rail transit park-and-ride lots. *ITE Journal,* Vol. 64, No. 6, 1994, pp. 34-41.
[72] Pehlke, L. O. Membership warehouse club trip generation study. *ITE Journal,* Vol. 64, No. 9, 1994, pp. 14-19.
[73] Van Winkle, J. W., and S. C. Kinton. Parking and trip generation characteristics for day-care facilities. *ITE Journal,* Vol. 64, No. 7, 1994, pp. 24-28.
[74] Hart, J., M. K. Kuntemeyer, and V. Torres-Verdin. Trip generation factors in Mexico City. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Denver, Colorado, United States, 1995.
[75] Szplett, D., and L. T. Kieck. Variations of trip generation and trip distance within the urban area. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Denver, Colorado, United States, 1995.
[76] Ewing, R., M. DeAnna, and S.-C. Li. Land use impacts on trip generation rates. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1518, 1996, pp. 1-6.
[77] Patel, M. I., F. J. Wegmann, and A. Chatterjee. Trip generation characteristics of economy motels. *ITE Journal,* Vol. 66, No. 5, 1996, pp. 21-26.
[78] Slipp, P. R. M., and J. E. Hummer. Trip generation rate update for public high schools. *ITE Journal,* Vol. 66, No. 6, 1996, pp. 34-40.
[79] Benway, P. F., and C. McCormick. Trip generation and travel characteristics associated with mega food markets. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Toronto, Ontario, Canada, 1998.
[80] Collins, T., and B. Collins. "Designing" trip generation rates from new residential areas. Presented at 22nd Australasian Transport Research Forum (ATRF), Sydney, Australia, 1998.
[81] Peterson, M. E., and F. E. Owsiany. Military housing trip generation study. *ITE Journal*, No. May 1998, 1998, pp. 90-93.
[82] Doyle, J. M. Trip generation for entertainment land uses. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Las Vegas, Nevada, United States, 1999.
[83] Heath, G. R., M. E. Lipinski, and J. W. Hurley. Trip generation rates for land based floating casinos (Tunica, Mississippi). Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Las Vegas, Nevada, United States, 1999.
[84] Jha, M. K., and D. J. Lovell. Trip generation characteristics of free-standing discount stores: A case study. *ITE Journal*, No. May 1999, 1999, pp. 85-89.
[85] Balmer, A. M., L. J. French, R. W. Eck, and J. Legg. Trip generation rates of consolidated schools. *ITE Journal,* Vol. 70, No. 8, 2000, pp. 30-34.
[86] Johnson, K. L., and M. I. Hammond. Trip generation characteristics for convenience stores. *ITE Journal,* Vol. 71, No. 8, 2001, pp. 26-30.
[87] Pitsiava-Latinopoulou, M., G. Tsohos, and S. Basbas. Trip generation rates and land use - transport planning in urban environment. *WIT Transactions on the Built Environment,* Vol. 52, 2001, pp. 297-306.
[88] Trueblood, M., and T. Gude. Trip generation characteristics of small to medium sized casinos. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Chicago, Illinois, United

States, 2001.
[89] Rowe, C. D., M. S. Kaseko, and K. W. Ackeret. Trip generation rates of consolidated schools. *ITE Journal,* Vol. 72, No. 5, 2002, pp. 26-33.
[90] Trueblood, M. Parking and trip generation characteristics of hospitals. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Seattle, Washington, United States, 2003.
[91] Gamas, J. A., W. P. Anderson, and C. Pastor. Estimation of trip generation in Mexico City, Mexico, with spatial effects and urban densities. *Transportation Research Record: Journal of the Transportation Research Board*, No. 1985, 2006, pp. 49-60.
[92] Miller, J. S., L. A. Hoel, A. Goswami, and J. M. Ulmer. Assessing the utility of private information in transportation planning studies: A case study of trip generation analysis. *Socio-Economic Planning Sciences,* Vol. 40, No. 2, 2006, pp. 94-118.
[93] Miller, J. S., L. A. Hoel, A. K. Goswami, and J. M. Ulmer. Borrowing residential trip generation rates. *Journal of Transportation Engineering,* Vol. 132, No. 2, 2006, pp. 105-113.
[94] Vivian, G. M. Trip generation characteristics of free-standing discount superstores. *ITE Journal,* Vol. 76, No. 8, 2006, pp. 30-32,37.
[95] DePaolis, J. M. Trip sharing between multiple retail developments in retail corridors. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Pittsburgh, Pennsylvania, United States, 2007.
[96] Flynn, T. E., and A. E. Boenau. Trip generation characteristics of age-restricted housing. *ITE Journal,* Vol. 77, No. 2, 2007, pp. 30-37.
[97] Al-Zahrani, A. H. M., and T. Hasan. Trip generation at fast food restaurants in Saudi Arabia. *ITE Journal,* Vol. 78, No. 2, 2008, pp. 24-29.
[98] O'Cinneide, D., and R. Grealy. Vehicle trip generation from retail, office and residential developments. Presented at European Transport Conference, Noordwijkerhout, The Netherlands, 2008.
[99] Morrison, S. J. Drive-in bank PM peak hour trip generation in the Portland metro area. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, San Antonio, Texas, United States, 2009.
[100] Pearson, D. F., B. S. Bochner, P. Ellis, and M. I. Ojah. Discount superstore trip generation. *ITE Journal,* Vol. 79, No. 6, 2009, pp. 20-24.
[101] Ratrout, N. T. Estimating grand mosque attraction of vehicular trips. *ITE Journal,* Vol. 79, No. 6, 2009, pp. 40-44.
[102] Dean, D., T. Dean, and A. Afridi. City of Surrey pick-up / drop-off trip generation study. Presented at Institute of Transportation Engineers (ITE) Annual Meeting, Vancouver, British Columbia, Canada, 2010.
[103] McCourt, R. S. Parking and vehicle trip generation for soccer fields and elementary schools. *ITE Journal,* Vol. 80, No. 8, 2010, pp. 34-38.
[104] Priyanto, S., and E. P. Friandi. Analyzing of public transport trip generation in developing countries; A case study in Yogyakarta, Indonesia. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering,* Vol. 4, No. 6, 2010, pp. 167-171.
[105] Ewing, R., M. Greenwald, M. Zhang, J. Walters, M. Feldman, R. Cervero, L. Frank, and J. Thomas. Traffic generated by mixed-use developments - Six-region study using consistent built environment measures. *Journal of Urban Planning and Development,* Vol. 137, No. 3, 2011, pp. 248-261.
[106] Greene, C., and V. Kannan. A trip generation study of coffee/donut shops in western New York. *ITE Journal,* Vol. 81, No. 6, 2011, pp. 40-45.
[107] Jeihani, M., and R. Camilo. Do retirement housing developments make fewer trips than regular housing? *ITE Journal,* Vol. 81, No. 6, 2011, pp. 46-49.
[108] Byrne, B., M. Carr, and J. Sumner. Preparation of the Vermont trip generation manual. *ITE Journal,* Vol. 82, No. 6, 2012, pp. 42-47.
[109] Findley, D. J., C. M. Cunningham, W. Letchworth, and M. A. Corwin. Predicting trip generation characteristics of power centers. *Journal of Transportation of the Institute of Transportation Engineers,* Vol. 4, No. 1, 2012, pp. 19-28.
[110] Jeihani, M., and R. Camilo. Town centers' trip generations. *ITE Journal,* Vol. 82, No. 6, 2012, pp. 32-35.
[111] Mahmoudi, J. Trip generation characteristics of super convenience market-gasoline pump stores. *ITE Journal,* Vol. 82, No. 6, 2012, pp. 16-21.

[112] Ko, J. Vehicle trip generation rates for office buildings under urban settings. *ITE Journal,* Vol. 83, No. 2, 2013, pp. 41-45.
[113] Zamir, K. R., A. Nasri, B. Baghaei, S. Mahapatra, and L. Zhang. Effects of transit-oriented development on trip generation, distribution, and mode share in Washington, D.C., and Baltimore, Maryland. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2413, 2014, pp. 45-53.
[114] Millard-Ball, A. Phantom trips: Overestimating the traffic impacts of new development. *The Journal of Transport and Land Use,* Vol. 8, No. 1, 2015, pp. 31-49.
[115] Onderwater, P. Public transport trip generation parameters for South Africa. Presented at 34th Southern African Transport Conference (SATC), Pretoria, South Africa, 2015.
[116] Tian, G., R. Ewing, A. White, S. Hamidi, J. Walters, J. P. Goates, and A. Joyce. Traffic generated by mixed-use developments: Thirteen-region study using consistent measures of built environment. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2500, 2015, pp. 116-124.
[117] Zimmerman, A. T. Hourly variation in trip generation for office and residential land uses. *ITE Journal,* Vol. 85, No. 1, 2015, pp. 20-22.
[118] Mousavi, A. A novel method for trip generation estimation using a prominent land use as a case study. *School of Civil Engineering and Built Environment, Science and Engineering Faculty, No. PhD*, Queensland University of Technology, Queensland, Australia, 2016.
[119] Al-Sahili, K., S. A. Eisheh, and F. Kobari. Estimation of new development trip impacts through trip generation rates for major land uses in Palestine. Presented at 7th Jordan International Civil Engineering Conference, Jordan, 2017.
[120] Al-Masaeid, O. M. Al Shehab, and T. S. Khedaywi. Trip and parking generation for shopping centers in Jordan. *ITE Journal,* Vol. 88, No. 2, 2018, pp. 45-49.
[121] Tian, G., K. Park, and R. Ewing. Trip and parking generation rates for different housing types: Effects of compact development. Presented at 97th Transportation Research Board (TRB) Annual Meeting, Washington, D.C., United States, 2018.
[122] Mousavi, A., J. Bunker, and B. Lee. Trip generation in Australia: Practical issues. *Road and Transport Research,* Vol. 21, No. 4, 2012, pp. 24-37.
[123] Milne, A., S. Abley, and M. Douglass. Comparisons of NZ and UK trips and parking rates. NZ Transport Agency, Wellington, New Zealand, 2009.
[124] Clark, I. Trip rate and parking databases in New Zealand and Australia. Presented at Australian Institute of Traffic Planning and Management (AITPM) National Conference, Canberra, Australia, 2007.
[125] Handy, S. Trip generation: Introduction to the special section. *The Journal of Transport and Land Use,* Vol. 8, No. 1, 2015, pp. 1-4.
[126] Broadstock, D. C., A. Collins, and L. C. Hunt. Modelling car trip generations for UK residential developments using data from TRICS. *Transportation Planning and Technology,* Vol. 33, No. 8, 2010, pp. 671-678.
[127] Bochner, B., K. M. Currans, S. Dock, K. J. Clifton, P. A. Gibson, D. K. Hardy, K. G. Hooper, L.-J. Kim, R. S. McCourt, D. R. Samdahl, G. H. Sokolow, and L. F. Tierney. Advances in urban trip generation estimation. *ITE Journal,* Vol. 86, No. 7, 2016, pp. 17-19.
[128] ITE Urban and Person Trip Generation Panel. Urban and Person Trip Generation. Institute of Transportation Engineers, Washington, D.C., United States, 2016.
[129] Douglass, M., and S. Abley. Trips and parking related to land use. NZ Transport Agency, Wellington, New Zealand, 2011.