Information Technology and Management Science
doi: 10.2478/itms-2013-0014
2013 / 16

Regression Analysis for Transport Trip Generation Evaluation

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***Abstract* – The paper focuses on transportation trip generation models based on mixed-use and transport infrastructure near the site. Transport trip generation models are considered with an aim to improve the accuracy of transport generated trips. Information systems are reviewed, and "smart growth" criteria that could affect the accuracy of trip generation models are also identified. Experimental results of transport generated trips based on linear regression equations and "smart growth" tools are demonstrated.**

***Keywords* – Information systems, linear regression equations, transport trip generation models**

I. Introduction

Trip generation model is the first step of the classic four-step transport model [10] – trip generation, distribution, mode choice and trip assignment. Trip generation models are divided into three levels: strategic, tactical and operational ones. Cross-classification models or category analysis [10] – [11] are used for trip generation calculations at the strategic and tactical levels. Linear regression models [4] and Rate methods with linear regression equations or with average rates are used to calculate transport generated trips at tactical and operational levels [5], [18], [19].

The aims of the paper are to review Rate methods for trip generation models and to evaluate "smart growth" tools to increase the accuracy of generated trip calculations with mixed-land use and transport infrastructure availability (public transport, pedestrians). All calculations are performed at the operational level and for trip attraction models.

II. Transportation Trip Generation Methods

Transport trip generation is the process of estimating daily or hourly person trips for an average weekday generated by households. Transport generated trips include two types of trips: trip production and trip attraction (Fig. 1).

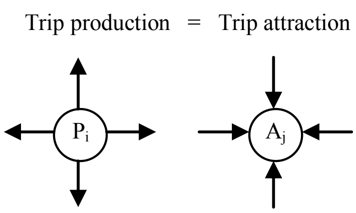


Fig. 1. Types of transport generated trips. Trip production models estimate the number of person trips generated by each household for each of the trip purposes and trip attraction models estimate the number of person trips attracted to each location

For each type of generated trips, there are various calculation methods (Fig. 2), but, as a result, the number of trip attraction should be the same as the number of trip production.

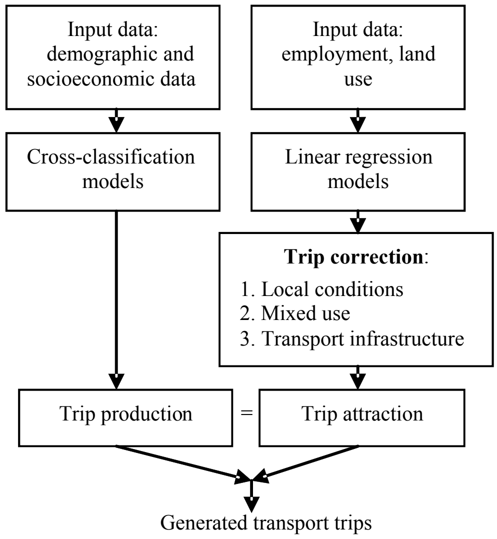


Fig. 2. Calculation process of generated transport trips

Rate methods with linear regression equations (1) are the most frequently used methods to evaluate the number of generated trips based on historical data. Transport generated trips are expressed as the number of trips per unit X, where X – the factor that describes the activity of land use, for example, for retail – the gross leasable area, for residential buildings – the number of apartments.

Linear regression equations evaluate the number of generated trips that attract research area (dependent variable) from independent variables

$$Y = a + b_1x_1 + b_2x_2 + \ldots + b_nx_n \quad , \qquad (1)$$

where Y – the dependent variable (trips/household), x_1, x_2 ... – independent variables (population, number of apartments, gross leasable area), b_1, b_2..b_n – regression coefficients that show to what extent Y changes, if x_n variable increases.

The current paper considers various information systems for trip generation calculation based on regression equations and/or average rates.

A. TRICS Information System

TRICS Information system [15] evaluates the transport capacity of a site on a street network based on the site functional data (retail, residential, office spaces), location (in the city centre or outside the city), analysed time period (peak hour, working day, weekend) and multimodal transport accessibility to an adjacent site. The main disadvantage of TRICS is the insufficient number of studies for specific land use categories that leads to low accuracy of generated trip calculations.

B. NZTPD and RTA Information Systems

NZTPD (New Zealand Trip Rate and Parking Database) [16] and RTA (Roads and Traffic Authority of New South Wales) [17] are widely used to estimate site impacts on transport infrastructure in New Zealand and the surrounding area. In [9] several types of land use – retail, residential, offices, medical buildings with TRICS information system – were compared and it was concluded that most land use characteristics are similar in both systems, especially for retail, and both systems could be used to calculate the number of generated trips.

C. ITE Trip Generation Information System

Trip generation information system is developed by the Institute of Transportation Engineers [18] and provides regression equations and average transport rates to estimate transport generated trips. The main disadvantage of ITE trip generation manual is the necessity of additional trip generation result corrections for adjacent sites and public transport availability near the site.

ITE trip generation manual regression equations for shopping centre are shown in Table I.

TABLE I

ITE TRIP GENERATION MANUAL REGRESSION EQUATIONS FOR SHOPPING CENTRE

Weekday morning peak hour trips	$Y = e^{0.6LN(X) + 2.29}$
Weekday evening peak hour trips	$Y = e^{0.66LN(X) + 3.40}$
Daily trips	$Y = e^{0.65*LN(X)+5.83}$
Weekend peak hour trips	$Y = e^{0.65*LN(X)+3.78}$
Average weekend trips	$Y = e^{0.63*LN(X)+6.23}$

where x – the shopping centre leasable area

Despite the fact that some information systems take into account the availability of transport infrastructure near the site and are used in different countries [2], it is necessary to take into consideration:

• different transport trip rates between cities, regions, countries;

• different demographic factors, living conditions, economic factors;

• different driving behaviours on roads (travel speed, interval between cars).

In this study, the automobilization level was used as an additional correction for local conditions.

III. ITE TRIP GENERATION INFORMATION SYSTEM AND "SMART GROWTH" TOOLS

Smart growth principles are strategies of transit-oriented and pedestrian-friendly mixed use lands for generated trips by reducing the number of cars in communities. ITE trip generation manual shows average daily and peak hours rates for transport generated trips (Fig. 3). All data are mostly provided for isolated areas without public transport and pedestrian infrastructure. In mixed-use conditions, the following steps are necessary to carry out for generated trip calculations:

1. calculate generated trips based on linear regression equations or average rates according to the ITE trip generation manual;
2. calculate the number of internal trips in the research area;
3. calculate the number of public transport trips;
4. calculate the number of hiking and cycling trips.

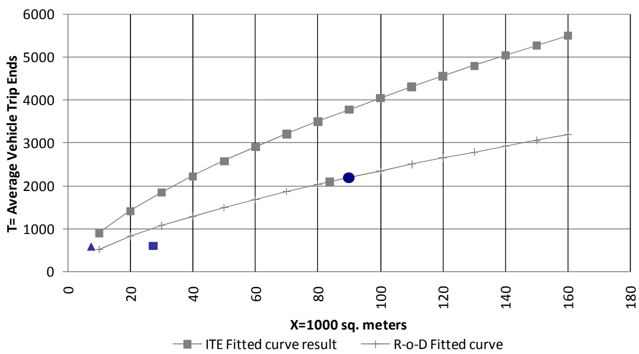


Fig. 3. Trip generation for shopping centre data

A. "Smart Growth" Tools for ITE Trip Generation Information System

"Smart growth" tools need to perform steps 2–4 mentioned above:

a) Mixed-use manual developed by ITE – it reduces the number of generated transport trips by reducing the number of internal trips between different types of land use.

b) Urbemis (urban emissions) program [7] – it estimates the influence of sites on the environment (air quality, the calculation of emissions) and evaluates the number of transport generated trips for different land use types (3) and takes into account information about public transport (4) and pedestrian activity (5).

$$\text{Trip Reduction} = \frac{\left| 1 - \frac{1.5h - e}{1.5h + e} \right| - 0.25}{0.0075}, \quad (3)$$

where h = housing units, e = the number of employed people in the research area.

$$\text{Trip Reduction} = 0.075\text{t} + 0.075 \cdot \text{p} \cdot \text{t} \quad , \quad (4)$$

where t = the index of public transport services.

$$\text{Trip Reduction} = \frac{0.09\,(\text{d}_\text{i} + \text{s}_\text{c} + \text{b}_\text{c})}{3} \quad , \quad (5)$$

where: d_i – the number of legs at intersections 2.5km^2, s_c – pedestrian way availability near the site, b_c – bicycle way availability near the site.

c) Mix-used trip generation model ERA MXD – it reduces the number of generated trips taking into account the mixed land use, number of employed people at the site and surrounding area (6).

$$\text{Trip Reduction} = \text{T}\ \ (1 - \text{p}_\text{i})\ \ (1 - \text{p}_\text{w} - \text{p}_\text{t}) \quad , \quad (6)$$

where T – the number of trips calculated by ITE trip generation information system, p_i – the probability of internal trips in the research area, p_w – the probability of external hiking or cycling trips, p_t – the probability of external public transport trips.

d) NCHRP 8–51 tool [8] – it estimates the number of internal transport trips between different types of land use and reduces the external transport generated trips by internal trip value (7).

$$\text{Trip Reduction} = \frac{\text{d}_1(\text{b}_1) + \text{d}_2(\text{b}_2)}{\text{c}}, \quad (7)$$

where b_1 – the space in building 1 of land use A, b_2 – the space in building 2 of land use A, c – the space in building 1 and 2 of land use A.

IV. Experimental Results

A. Initial Data

Four sites with mixed land use and with gross leasable area from 29 to 60 thousand m^2 were used in this study (Table II). The number of employed people outside the sites was calculated according to Riga City Development Plan for 2006–2018. Number of intersections, as well as percent of streets with sidewalks was determined using publicly available maps of the city. Number of public transport vehicles was calculated according to local municipality data; all calculations were made for evening peak hours.

TABLE II

Initial Data for Trip Generation

	Gross leasable area, м^2	Actual generated trips, evening peak hours	Remarks
Mixed use 1	32 000	1087	Improvements in transport accessibility near the site (additional left turn, Fig. 3)
Mixed use 1a	32 000	1462	
Mixed use 2	22 000	1190	
Mixed use 3	40 000	1593	The increase in gross leasable area
Mixed use 3a	60 000	2025	

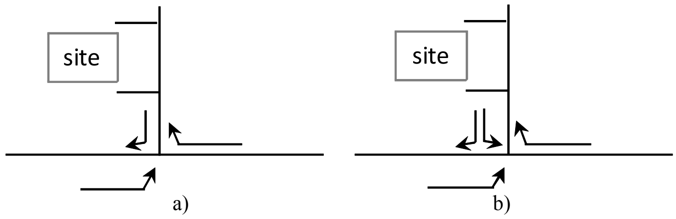


Fig. 4. Transport accessibility: a) traffic organization scheme for mixed use 1; b) traffic organization scheme for mixed use 1a

B. Results

Transport generated trips were calculated according to TRICS, NZTPD and ITE trip generation information systems (Table 3). Additional corrections for "smart growth" based on Urmebis, ERA MXD and NCHRP 8–51 tools were considered for ITE trip generation information system. Per cent error as a difference between observed and actual values for each information system was determined.

$$\text{Error} = \frac{\text{observed - actual}}{\text{actual}} \cdot 100 \quad (8)$$

Percent errors between observed and actual transport generated trips for evening peak hours for four mixed-use sites are shown in Table III.

TABLE III

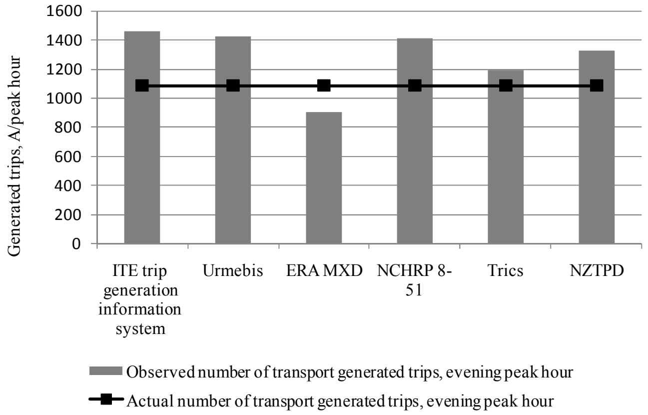
Percent Error between Observed and Actual Transport Generated Trips for Evening Peak Hours

Mixed use	Observed trips, A/pm	ITE	ITE with correction, A/pm			TRICS	NZTPD
			Urmebis	ERA MXD	NCHRP 8–51		
1	1087	34%	31%	17%	30%	**10%**	22%
1a	1462	**0%**	3%	38%	3%	18%	9%
2	1190	**5%**	9%	28%	6%	31%	6%
3	1593	6%	**0%**	13%	1%	6%	4%
3a	2025	10%	**3%**	13%	7%	10%	23%

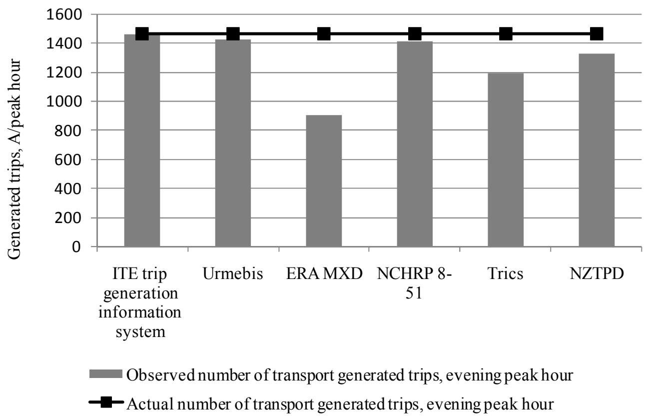
where A/pm – the number of transport generated trips for evening peak hours.

The most accurate results were shown by TRICS information system (Fig. 5, a) with 10% error and the ITE trip generation information system with additional correction by

ERA MXD "smart growth" tools with 17% error for mixed use 1. Increasing the transport accessibility (Fig. 5, b) near the site, changing traffic organization at adjacent intersection from mixed use 1, the best result was shown by the ITE trip generation information system without any correction for public transport and pedestrians – trip generation result accuracy was 99.6%. High calculation accuracy without any additional corrections of the ITE trip generation information system are related to the fact that mixed-use lands 1 are located near the freeway and till recently transport accessibility from the site to the freeway was restricted (Fig. 4, a). After allowing the additional left turn from the site to the freeway (Fig. 4, b), percent error significantly decreased for the ITE trip generation information system without corrections and for the ITE system with such "smart growth" tools as Urbemis and NCHRP 8-51 was in the range of 0%–3%. If we take into account the accessibility of transport infrastructure near the site (pedestrians, public transport, other sites near the mixed use 1), percent error for generated trips grew and for such "smart tools" as Urbemis and NCHRP 8-51 was 30%.



(a)



(b)

Fig. 5. Transport generated trips: a) mixed use 1; b) mixed use 1a

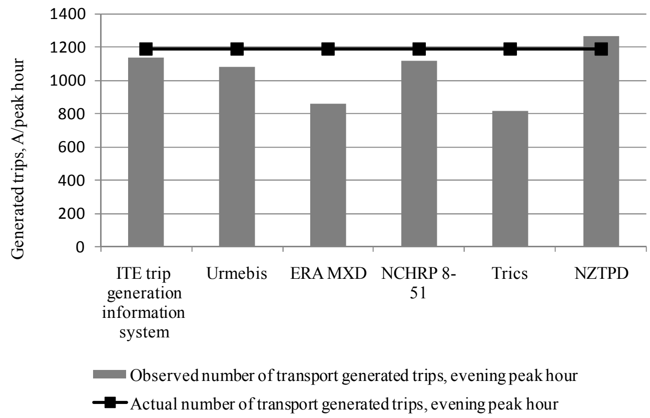
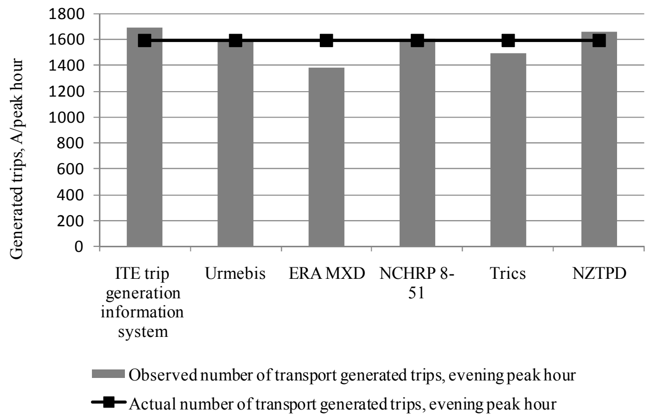


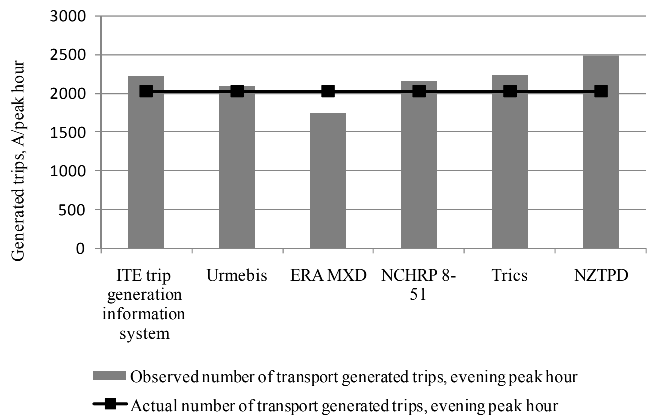
Fig. 6. Transport generated trips. Mixed use 2

For mixed land use 2, the ITE trip generation information system without additional corrections, ITE with NCHRP 8-51 "smart growth" tool and NZTPD information system showed the best results with percent error of 6% for generated trips (Fig. 6).

Mixed land use 3 and 3a provide an increase in the gross leasable area without changing transport accessibility near the site. Accuracy of generated trip calculations for mixed land use 3 (Fig. 7, a) with the ITE trip generation information system and such "smart growth" tool as Urbemis was 99.9%.



(a)



(b)

Fig. 7. Transport generated trips: a) mixed use 3; b) mixed use 3a.

High accuracy of calculations is related to mixed land location – outside the city centre with a good public transport network and pedestrian walkways. Percent error for mixed land use 3a increased in the range of 3%–20% (Fig. 7, b) following an increase in the gross leasable area.

According to transport trip generation calculations, it could be seen that the presence or absence of public transport network and walkways near the site influenced accuracy in the range of 3%–10%.

Trip generation results with the ITE trip generation information system without additional corrections, TRICS and NZTPD information systems did not show the one best method or tool for local conditions. For transport trip generation under local conditions, the most acceptable tool can be considered the ITE trip generation information system with additional corrections by Urbemis "smart growth" tool.

V. Conclusion

Transportation trip generation models were evaluated taking into account the mixed land use and transport infrastructure availability in the research area. The number of transport generated trips was calculated based on linear regression equations. Accuracy of generated trips per hour was maximized by the evaluation of "smart growth" criteria.

Results of the considered mixed lands use showed that there was not the one best solution for transport generated trip calculations. The most reliable results were shown by the ITE trip generation information system with additional correction by Urbemis with percent error up to 3%, for some mixed land use accuracy was 99.9%. The complexity of "smart growth" tool Urbemis application is that the number of reduced trips is shown in the daily section and not calculated for the peak hours.

Criteria of smart growth, such as the number of employed people, public transport availability, walkability near the research land use, and transport accessibility, could significantly improve or decrease results of calculations of generated trips for the transportation model, available initial data, chosen linear regression equations and type of mixed land use basis.

TRICS and NZTPD information systems showed insignificant accuracy of generated trip calculation; percent error ranged from 6% to 30%. The reasons of such results could be the small number of information system observations for chosen conditions, incorrect adjustments for local conditions and inaccuracy in input data.

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Nadežda Zeņina, Arkādijs Borisovs. Regresijas analīze transporta braucienu skaita novērtēšanai

Transporta attīstības pārvadājuma modeļi – pirmais solis klasiskajā četrsoļu transporta modelī: ģenerēto transporta braucienu aprēķins, transporta sadalījums, transportlīdzekļu tipa izvēle (piem., privātais un sabiedriskais transports) un transporta norīkojums saskaņā ar izvēlēto transporta tipu. Rakstā ir izpētīti transporta attīstības pārvadājumu modeļi, lai uzlabotu ģenerētās transporta plūsmas aprēķina precizitāti, ņemot vērā jaukto apbūvi un transporta infrastruktūras (sabiedriskais transports, gājēji) pieejamību. Veikts informācijas sistēmu apskats (Trics, ITE, NZTPD) un izskatīti «smart growth» (Urmebis, ERA MXD, NCHRP 8-514) instrumenti, kuri ļauj uzlabot ģenerētās transporta plūsmas aplēses apjomus tuvāk novērojamiem. Stratēģijas «smart growth» mērķis mazināt transporta braucienu skaitu pēc principa – augstie apbūves blīvumi kopā ar jauktās zemes izmantošanu. Analīze veikta taktiskajā līmenī. Nodemonstrēti ģenerētas transporta plūsmas eksperimentu rezultāti uz lineāras regresijas vienādojumu un «smart growth» instrumentu pamata. Analīzes rezultāti uzrādīja, ka nav viena vienīga labāka risinājuma no izskatītajiem ģenerētās transporta plūsmas novērtējumam. Rezultātu precizitāti ietekmēja ne tikai dati par iedzīvotāju nodarbinātību, sabiedriskā transporta esamību, bet arī ierobežojumi transporta infrastruktūrā un infrastruktūras pieejamības paaugstināšana (jauni atļauti kreisie manevri transportlīdzekļu kustībai). Informācijas sistēmas TRICS un NZTPD uzrādīja zemu ģenerētas transporta plūsmas precizitāti, kļūda starp aprēķina un novērojumo transporta plūsmu sastādīja 6% - 30%. Viens no iemesliem zemajai precizitātei ir neliels datu izlases apjoms. Analīzes rezultāti uzrādīja, ka slikti attīstīts sabiedriskā transporta un gājēju tīkls izpētes objekta tuvumā var samazināt ģenerētas transporta plūsmas precizitāti par 3% -10%. Pielietojot ITE metodi kopā ar Urbemis instrumentu, transporta ģenerēto braucienu skaita aprēķina precizitāte sastādīja 99.9% (atsevišķām būvēm). Augsta precizitāte ir saistīta ar izpētes objekta izvietojumu pilsētā – pilsētas malā ar labi attīstītu sabiedriskā transporta un gājēju tīklu.

Надежда Зенина, Аркадий Борисов. Регрессионный анализ в оценке количества транспортных поездок

Модели развития транспортных перевозок - первый шаг классической четырехступенчатой транспортной модели: расчет генерируемых поездок, распределение транспортных потоков, выбор вида транспортного передвижения и распределение потоков с учётом выбранного вида передвижения. В работе исследованы модели развития транспортных перевозок на предмет повышения точности расчёта генерированного транспортного потока в условиях смешанной застройки и наличия транспортной инфраструктуры (общественный транспорт, пешеходы). Произведён обзор информационных систем (Trics, ITE, NZTPD) и рассмотрены инструменты «smart growth» (Urmebis, ERA MXD, NCHRP 8-514), позволяющие скорректировать расчётные объёмы генерированного транспортного потока ближе к наблюдаемым. Стратегия «smart growth» включает в себя сокращение количества транспортных поездок на автомобиле по принципу - высокие плотности застроек со смешанным землепользованием. Анализ проведён на тактическом уровне. Представлены экспериментальные результаты генерированного транспортного потока на основе уравнений линейной регрессии и инструментов «smart growth». Результаты анализа показали, что нет одного лучшего метода из рассмотренных для расчета генерированного транспортного потока. На точность расчетов генерируемого потока повлияли не только сведения о занятости населения, пешеходах и общественном транспорте вблизи от объекта, но и ограничения/увеличение транспортной доступности. Информационные системы TRICS и NZTPD показали невысокую точность расчета генерируемого транспортного потока, ошибка между ожидаемым и наблюдаемым потоком составила 6% - 30%. Одной из причин невысокой точности является небольшой объём выборки информационных систем для рассмотренных условий (торговые объекты недвижимости, с общей площадью 20-40тыс м2). Анализ результатов показал, что наличие или отсутствие вблизи смешанной застройки развитой сети общественного транспорта влияет на точность расчета генерируемого транспортного потока в пределах 3% - 10%. Применение ИТЕ метода с инструментом Urmebis для трёх смешанных застроек обеспечило приемлемую точность расчетов генерируемого транспортного потока (для отдельных смешанных застроек точность расчётов составила 99,9%).