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Establishing parking generation rates/models of selected land uses for Palestinian cities

Khaled Al-Sahili [a,*], Jamil Hamadneh [b]

[a] Civil Engineering Department, An-Najah National University, P.O. Box 7, Nablus, Palestine
[b] Traffic Higher Council, Ministry of Transport, Ramallah, Palestine

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ABSTRACT

Estimating parking demand in Palestine requires more oriented studies towards parking generation to enrich transportation planning, design, and management. Using regional or international models and rates of parking demand may not be appropriate for Palestine. This research is conducted to establish a reference for provision of parking supply for three major types of land uses, which are residential, office, and retail.

Seventy-three sites of different land uses were selected through field investigations, interviews, and availability of information for each site. The study covered all main cities in the West Bank, Palestine. Data collection was conducted manually, which contains site characteristics and average of two-day parking counts during three periods (AM, PM, and Peak of the Development).

Numerous models and rates were investigated yielding variable statistical accuracies. Most appropriate statistical models/rates were summarized and highlighted for each type of land use, and parking generation models with acceptable statistical significance were recommended, otherwise, parking generation rates were recommended. Simple linear regression, natural logarithmic linear regression, and power were the forms of the recommended models for the studied land uses.

This study forms the first step of a future Palestinian "*Parking Generation Manual*" that should contain various local land use types.

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1. Introduction

Parking and trip generation rates/equations are used to evaluate the requirements of transportation network such as the right of way adjacent to specific land use or the maximum traffic volume that should not be exceeded on the adjacent street, as well as size of parking facilities for each type of land use. Excessive on-street parking supply may negatively affect the level of service of road network due to the resulted obstructions from parked vehicles. Furthermore, deficiency in providing sufficient off-street parking spaces for certain land uses creates negative economic impacts. On the other hand, the size of parking supply might exhaust road network and negatively affect its operating level of service. In essence, establishing parking generation for different land uses contribute in managing and controlling real estate and parking supply for each land use, and consequently avoiding congestion generated by parking.

* Corresponding author.
E-mail addresses: alsahili@najah.edu (K. Al-Sahili), jameelhamadneh@yahoo.com (J. Hamadneh).

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Trip and parking generation contributes in the formation of urban areas (Urban Morphology) and supports the decision makers in the planning of urban areas. For example, changing the land use pattern of specific area from residential to commercial will affect traffic on the adjacent road network system; but at what level this effect will be?

Main cities in Palestine suffer from congestion at critical sites due to improper planning for parking facilities, among others, for new developments. As a result, this guides transportation planners in managing the transportation system and assists them in their planning decisions. Furthermore, this study assists the key stakeholders (i.e., government agencies) to institutionalize the adoption of Traffic Impact Studies (TIS) and update any available regulations regarding parking facilities.

The State of Palestine has some standards/regulations related to parking spaces required for certain new developments, and these standards were set by municipalities, the Ministry of Local Government (MoLG), and Engineers Association (AE). These standards are not based on specialized studies and may not consider the detailed characteristics of land use types; furthermore, they are outdated as they are based on old requirements.

In this study, Parking Generation for residential, retail, and office land uses were undertaken. Similar work has been done in several cities, states, provinces, etc. around the world, but in Palestine it is still lacking of this type of study. Studies conducted abroad cannot be applied as a whole locally due to some factors such as travel habits, economic size, developments types, sizes, political conditions, and others.

The State of Palestine has unique characteristics. It is a state under establishment with an economy in transition. Income level is modest and the Palestinian National Authority has limited control on land, and no control on border, air, and sea. It is simply a state with severe political and economic constraints; at the same time car ownership has rapidly increased in recent years due to banks financial facilitation, among others. Furthermore, necessary information is generally limited or lacking. Therefore, it is necessary to conduct and establish local parking generation rates/equations for Palestinian cities in order to form an initial stage of developing a local parking generation guide or manual.

As such, this is the first study in the country of its type, and it is comprehensive as it covers major land uses and all main cities in the West Bank (see Fig. 1). In addition, this research assists in developing strategies for mitigating their adverse impacts.

2. Literature review

The 4th edition of the Institute of Transportation Engineers (ITE) Parking Generation manual involves 69 land use classifications; it represents a collection of data since 1978 (ITE, 2010).

Parking generation produced various levels of statistics ranging from poor to good. For example, when using the gross floor area (GFA) with parking demand it produces high coefficient of determination; however, when using number of employees it produces low coefficient of determination. The ITE concluded that homogeneous data sets or small data sets may produce low coefficient of determination and does not necessarily mean more reliable relationship (ITE, 2010).

The ITE (2010) also provides information and guidelines about site selection, permissions, procedure, background, and independent variables. For example, parking generation for residential land uses is expressed in terms of dwelling units, persons, vehicles, and areas as independent variables; office land use in terms of employees and area; and retail land use in terms of employees and areas.

Douglass and Abley (2011) prepared a research study to compare New Zealand, Australia, UK, and USA information on trip and parking related to land uses, and reviewed current trip generation survey and data manuals from these four countries. The research considered seasonal traffic and parking variations and identified the practical parking design demand for a whole year as the 85th percentile satisfaction, which is also the 50th highest hour. Independent variables such as GFA, gross leasable floor area, which is commonly 80% of the GFA, site area, employees, and activity units were derived from survey process. The study concluded that the most practicable unit for most district plans is still spaces per 100 m^2 GFA (Douglass and Abley, 2011).

Regidor and Regin (2010) assessed some issues pertaining to local trip and parking rates in Philippine. Parking generation in Philippines used a number of relevant laws pertaining to the provision of off-street parking for different types of developments, and among these is the National Building Code of the Republic of the Philippines. The study identified several parameters for parking requirements for such developments such as gross floor area, gross saleable area, floor area ratio (density), parking slot cost, and distance from the central business district (CBD).

The Roads and Traffic Authority (2002) of Australia established a guide that outlined various considerations of traffic generation relating to developments. This guide sets out the range of parking demands likely to occur at an isolated site, recognizing the impact it may have on transport policy and travel demand. Parking provision should be viewed as the minimum desirable requirement, while Councils' Parking Codes are considered to be minimum mandatory requirements. The parking provisions recommended are based, wherever possible, on physical characteristics of the proposed development, particularly the gross floor area. The Roads and Authority used 85th percentile level of demand in parking demand estimation.

The Department of Transport of Abu Dhabi prepared a manual for estimating the parking and trip generation rates for several local land uses through the survey on nearly 400 different sites throughout the Emirate. Parking generation rates covered all types of predominated land uses in Abu Dhabi. The manual covered three locations in the Emirate, which are Abu Dhabi City, Al-Ein City, and Others for sites in the CBD and non-CBD areas (The Department of Transportation Abu Dhabi, 2012).

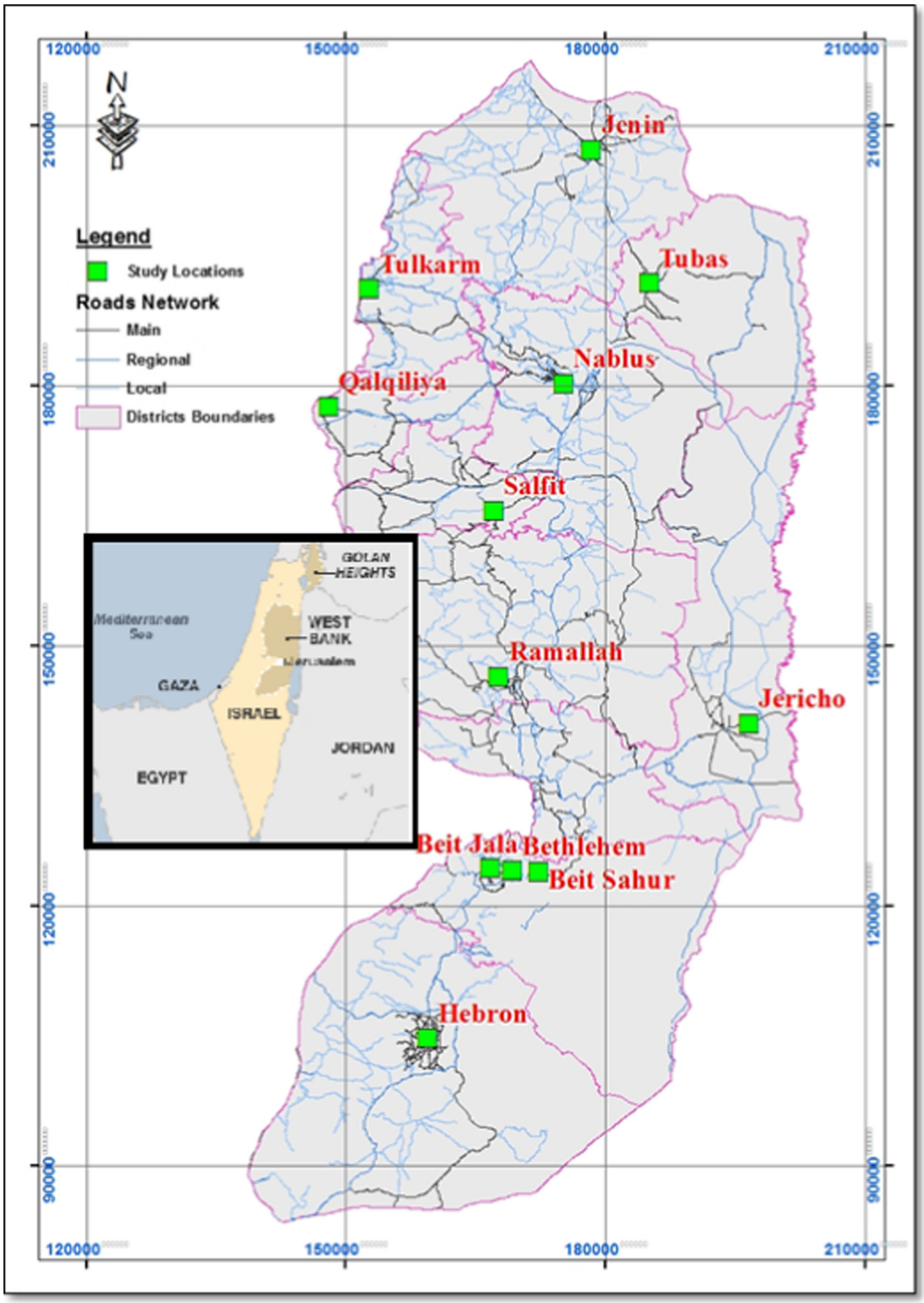

Fig. 1. Study area. Source: (Ministry of Local Government, 2015).

Al-Masaeid et al. (1999) developed statistical models for estimating vehicle parking demands of different land uses in several cities in Jordan. These land uses include 53 hospitals, 40 hotels, 42 office buildings, 35 apartment buildings, 21 restaurants, and 17 shopping centers, for a total of 208 sites. Three criteria were adopted in the selection process. First, each

selected site must have a well-defined parking lot and the parking is not permitted to be used by adjacent land uses. Second, the sites should be located in different cities. Third, the parking lot should have an adequate parking supply. All selected sites were located outside the CBD's. The developed models had an exponential form, except for models of restaurants and shopping centers, which had a linear form. The researchers concluded that compared with the standard values for developed countries, the parking demands for the investigated land uses in Jordan had lower rates.

Ordinances were developed and used by the Ministry of Local Government (MoLG) and municipalities in Palestinian localities regarding provision of parking supply. Local small scale studies were conducted by few agencies/organizations in specific sites in the West Bank. Al-Sahili (2010) performed parking and traffic counts adjacent to residential, hotel, office, and shopping/retail center land uses to capture trips and parking associated with the particular land use. Five land uses were surveyed during the AM peak and PM peak periods of a typical workday. In addition, the study evaluated the proposed parking supply against the parking requirements established by MoLG in Palestine. The study concluded that the local parking requirements may not be suitable for mix land uses.

The Palestinian Buildings System and Regulations for Local Government Units (LGU's) (Ministry of Local Government, 2011) is the only system used locally in Palestine by planners and LGU's for estimating parking requirements for various land uses. For residential land use class (A, B, and high rise buildings) one space for each dwelling unit is required. While for Class C, D, and old city one space for each two dwelling units is required. Retail land use should provide one space for each 50 square meter of stores and exhibits one additional space for other uses (other than stores). For each 70 square meter (sq. m) of office land use one space should be provided. However, these regulations were not based on studies and are relatively outdated as they were depicted from older regulations.

3. Research methodology

The primary aspect of the used methodology is conducting parking demand survey for the selected land uses and estimating the parking generation rate or equation. This is done in the following manner.

3.1. Data collection

In addition to the desk review, field surveys were conducted for the selected sites taking into consideration the study variables, sample size determination, and the selection of appropriate sites.

3.1.1. Land use classification

Based on the local experience and the existing environment in Palestinian cities, investigation of residential, retail, and office land uses showed that these land uses can be classified into classes. Residential land use type was classified into attached housing (AH), detached housing (DH), and apartments (APH). Office land use was classified based on its nature and services they provided as general, institutional, and government classes. Retail land use was classified into strip retail, shopping center, and medium to large supermarket.

3.1.2. Site selection

The adopted methodology for selecting sites in this research was based on the criteria set by the ITE (2010) and Al-Masaeid et al. (1999):

- Site should be mature (i.e., at least two years old).
- Occupancy (i.e., at least 85%).
- Sites should be clear for the purpose of controlling parking counts on it.
- No abnormal condition besides selected site such as constructions.
- Accessible by the surveyors for collecting whole information.

3.1.3. Sample size

The ITE stated that sample size of at least four should be analyzed to develop regression model (McCourt, 2004). Furthermore, selected developments should have single land use as this research focuses on single land use rather than mixed uses.

3.1.4. Filtering/screening

From among large number of visits for proposed sites, only specific number of sites for each land use was selected based on the predefined criteria to ensure the suitability of a site for conducting the study. Selection of sites was based on visual inspection and interviews.

3.1.5. Interviews

Interviews were held with people who have the merit of providing information about the surveyed development/site. Feedback about their particular requirements to conduct traffic count was taken into consideration before conducting the survey, and their permission for conducting the traffic count was obtained.

3.1.6. Survey period

At least two peak periods were identified and counts based on 15-min time interval were conducted to capture the variation within the study period. As counting interval decreases the probability of detecting the maximum accumulation increases, especially when the parking time of parked vehicle is small. Furthermore, this study covers only typical weekdays (Monday, Tuesday, and Wednesday), and it does not take into account the weekends, holidays, and any abnormal day through the week. It should be noted that working days in Palestine are Sunday through Thursday.

In order to identify the time of maximum accumulation, inventory study was conducted to minimize counting duration, and consequently, saving efforts. The survey periods were 7:00–9:00 AM and 2:00–5:00 PM for the peak of adjacent streets, in addition to the peak parking time of the development itself, if it is different than the peak of the adjacent streets.

3.1.7. Survey form

After conducting a pilot study on a small sample of land uses, the final survey forms were prepared and used. Two forms were used: parking accumulation form and site/development information form.

3.2. Data analysis process

Parking accumulation is the number of parked vehicle at a specified time (Garber and Hoel, 2010). It provides maximum parked vehicles during counting periods (AM, PM, and both). Average maximum parking accumulation represents the average maximum parked vehicles during the two count days.

Different types of regression models were investigated such as linear, logarithmic, power, and exponential as shown below.

$$P = \beta 1 * X_1 + C \quad \text{(Linear)}$$
$$Ln(P) = \beta_1 * Ln(X) + C \quad \text{(Power)}$$
$$Ln(P) = \beta_1 * X + C \quad \text{(Exponential)}$$
$$P = \beta_1 * Ln(X) + C \quad \text{(Logarithmic)}$$

P: parking demand (dependent variable).
X: independent variable.
β_1: variable coefficient (slope).
C: constant (intercept).

The independent variables (parameters) vary and depend on the type of each land use pattern. For example, for retail land use, gross floor area (GFA), gross leasable area (GLA), and number of employees may be used as independent variables. Based on the ITE (2010) methodology, simple regression with one independent variable, which minimizes the least square error of the model, was used in developing the model. Best fit or regression line expressed by coefficient of determination (R^2) stands for the line that matches largest number of points. Distances between points and line should be minimized for regression line and these distances are the error.

R^2 or adjusted R^2 measures the goodness of fit of the developed model. The adjusted R^2 adjusts the values of R^2 when sample size is small because the estimated R^2 of small sample size tends to be higher than actual R^2 for the population. Adjuster R^2 is used when it differs by large amount from R^2 (Green and Salkind, 2010). R^2 is used to express the variation in the percentage of number of parked vehicles associated with the variance in the sample size of independent variable (McCourt, 2004). As stated by ITE (2010), it is preferable to use R^2 when there is sufficient sites and R^2 is larger than 0.5.

Rates, which represent the average weighted mean, are predominately used in several locations around the worlds, for example, UAE, Australia, and USA. Rates could be used when the developed model does not have the power to predict.

Statistical tests were checked for each model and rate to ensure the accuracy of the produced model or rate in prediction. Analysis of Variance (ANOVA) provides information on how the regression equation accounts for variability in the independent variable. F-test is used to test the significance of the generated model at predefined confidence level; the reliability of the developed models depends on this test (Montgomery and Runger, 2002).

T-test was used to test the hypothesis about coefficients included in the generated model by checking the significance of coefficients included in the developed model. Test of hypotheses can be done using the *T*-test null hypothesis (H_0), which is whenever a coefficient is not significant and does not impact the model at predefined confidence level. On the other hand, alternative hypothesis (H_1) shows that the coefficient is significant and affects the model (Montgomery and Runger, 2002). The Statistical Package for the Social Sciences (SPSS) was used to conduct the statistical analyses for the investigated models and rates.

4. Data collection

Only sites that comply with the predefined criteria were selected. In each land use type, a sample size of more than the predefined minimum by ITE (2010) was used. In this research, 5 or more sites for each of studies land use classes were selected to the conduct parking generation rates or equations.

The residential land use sites were 8 DH, 5 AH, and 10 APH. Office land use sites were 14 government office, 7 institutional office, and 5 general office. Retail land use sites were 17 supermarkets, 9 strip retail, and only one shopping center; the only one available in the West Bank. These land uses were located in non-CBD urban areas and isolated from overlapping activities with other land uses.

The selection of the sample size for each land use and its classes was constrained by the availability of sites that satisfy the site selection criteria, the geographic distribution of sites throughout the country, and time and budget constraints. It should be noted that the attached housing is not a common type in Palestinian cities, in addition it was difficult to find a single use general office; it was mostly mixed use.

Table 1 shows the sample size of each land use class and the associated characteristics.

4.1. Parking accumulation

Parking accumulation of each class of land use was counted manually for two days and for at least two peak periods (AM & PM) of the adjacent streets in each day. Parking demand herein represents the average peak value of the two-day counts. On the other hand, the maximum parking demand is the maximum of the development. Tables 2–4 present the parking demand for the studied land use classes.

It should be noted that the residential land use peak demand periods coincide with the peak traffic of the adjacent street. However, for retail and office land uses, the maximum peak may not coincide with the peak of the adjacent streets; therefore, the maximum parking demand was identified, in addition to the AM and PM peaks, as shown in Tables 3 and 4.

4.2. Developed parking generation models and rates

Selection of the best model was based on statistical parameters such as residuals plot, confidence level, R^2, and RMSE (standard error of the estimate) (Shacham et al., 1996). Table 5 shows a sample of most appropriate model forms achieved, which produced the best statistical results, for attached housing. Although these were the most appropriate models reached for the particular land use, however, not all of them were statistically significant as apparent from the low t- and F-statistics. Therefore, such models were not recommended.

Tables 6–8 show the produced rates and models that are recommended to be used in predicting parking demand for the three types of land uses and their classes. It should be noted that models that produced R^2 less than 0.60 are not reported.

As for shopping center class, only one site is available in the study area. Therefore, only the rate is used in predicting the maximum parking generation, which is 2.25 parked vehicles per 100 m^2 of GFA or 2.94 parked vehicles per 100 m^2 of GLA.

The parking generation results of models and rates were compared using sample points within the range of data used. It was found that, in general, both rates and models were reasonably consistent for residential and retail land use classes taking into consideration the coefficient of determination for the models. However, there were large differences for general and institutional office classes, while institutional office class showed large differences for minimum values of the independent variables. This can be explained by the relatively small sample size for the general and institutional office classes. Therefore, it is recommended to rely more on the parking rate for the office land use.

5. Model/rate verification

Verification of the attained models and rates are checked based on random samples; this sample was selected for studied land use classes to estimate the parking demand and make inferences about the differences between the observed values and the model's estimated value. The verification was tested only for the most appropriate model form(s) for each land use class,

Table 1
Summary of data for study land uses and their classes.

Land use type	Land use class	Sample size	Range of inhabitants/ workers	Range no. of occupied dwelling units	Range no. of dwelling units	Range of owned vehicles	Range of GFA (m^2)	Range of GLA (m^2)
Residential	Attached housing	5	59–180	13–36	13–36	10–30	–	–
	Detached housing	8	28–308	7–76	7–76	9–141	–	–
	Apartment housing	10	70–384	14–64	16–77	4–39	–	–
Office	General office	5	23–45	–	–	10–21	540–1655	380–1425
	Institutional office	6	12–600	–	–	8–275	250–12,500	250–12,500
	Government office	15	22–190	–	–	6–45	400–3950	300–3950
Retail	Supermarket retail	17	2–15	–	–	1–7	110–1200	110–1200
	Strip retail	8	5–28	–	–	3–17	180–1200	180–1200
	Shopping center	1	37	–	–	20	5500	4200

Table 2
Residential land use parking accumulation (parked vehicle).

No.	Land use class	Parking demand (AM)	Parking demand (PM)
1	Attached housing	23	13
2	Detached housing	32	29
3	Apartments housing	15	16

Table 3
Office land use parking accumulation (parked vehicle).

No.	Land use class	Parking demand (AM)	Parking demand (PM)	Max. parking demand
1	General office	14	18	18
2	Institutional office	57	57	61
3	Government office	21	21	24

Table 4
Retail land use parking accumulation (parked vehicle).

No.	Land use class	Parking demand (AM)	Parking demand (PM)	Max. parking demand
1	Supermarket retail	16	15	18
2	Strip retail	10	10	11
3	Shopping center	120	124	124

Table 5
Sample of investigated parking generation models for ah residential land use class in AM and PM periods.

Period	Regression model	R^2	F-test		*t*-test		Std. error of the estimate	Independent variable
			F	Sig.	*t*	Sig.		
AM	$P = 0.911 * X + 1.323$	0.41	2.12	0.241	0.085	0.938	10.2	Number of occupied units
	$P = 0.204 * X + 0.849$	0.66	5.78	0.096	0.086	0.937	7.8	Number of inhabitants
PM	$P = 2.66 * X^{0.516}$	0.28	1.159	0.361	0.651	0.561	0.35	Number of occupied units
	$P = 0.708 * X^{0.635}$	0.56	3.83	0.145	−0.229	0.833	0.27	Number of inhabitants

Table 6
Parking generation models/rates for residential land use.

Class	Period	Independent variable	Model	R^2	Rate
Attached housing	AM	Number of occupied units	–	–	0.95 space/occupied unit
		Number of inhabitants	$P = 0.204 * X + 0.849$	0.66	0.21 space/inhabitant
	PM	No. of occupied units	–	–	0.55 space/occupied unit
		Number of inhabitants	–	–	0.12 space/inhabitant
Detached housing	AM	Number of occupied units	$P = 0.914 * X^{0.911}$	0.82	0.93 space/occupied DH unit
		Number of inhabitants	$P = 0.157 * X^{1.065}$	0.91	0.22 space/inhabitant
	PM	Number of occupied units	–	–	0.82 space/occupied unit
		Number of inhabitants	$P = 16.781 * \ln(x) - 50.38$	0.67	0.20 space/inhabitant
Apartments	AM	Number of inhabitants	–	–	0.09 space/inhabitant
		GFA (m^2)	–	–	0.33 space/100 GFA
		Number of occupied DU's.	–	–	0.51 space/occupied DU
	PM	Number of inhabitants	–	–	0.09 space/inhabitant
		GFA (m^2)	–	–	0.33 space/100 GFA
		Number of occupied DU's	–	–	0.49 space/occupied DU

and based on the availability of samples for verification as well as for models where the sample size, based on which the model was developed, was reasonable.

If the estimated values from models coincide or are close to the observed values, the models can be considered verified. For the purpose of this research and according to the studied sample sizes, 30% of difference is considered acceptable.

Table 9 shows the verification results for the most appropriate form of the model for the studied land uses, and where the model is recommended over the rate. Based on these results, it can be considered that the models are generally verified as the differences are less than 30%. An exception to this was the general office model based on the workers' vehicles in the AM peak period. Therefore, the models can be considered verified.

Table 7
Parking generation models/rates for office land use.

Class	Period	Independent variable	Model	R^2	Rate
General office	Peak	Number of workers	–	–	0.52 space/worker
		GFA (m^2)	$P = 27{,}502 * X^{-1.072}$	0.93	1.57 space/100 sq. m GFA
		GLA (m^2)	$P = -17.62 \ln(x) + 137.32$	0.88	1.81 space/100 sq. m GLA
		Number of workers' vehicles	$P = -28.51 \ln(x) + 96.07$	0.78	1.09 space/worker vehicle
	AM	Number of workers	–	–	0.39 space/worker
		GFA (m^2)	–	–	1.18 space/100 sq. m GFA
		GLA (m^2)	–	–	1.37 space per 100 sq. m GLA
		Number of workers' vehicles	–	–	0.82 space/worker's vehicle
	PM	Number of workers	–	–	0.51 space/worker
		GFA (m^2)	$P = 61{,}945 * X^{-1.193}$	0.98	1.54 space/100 sq. m GFA
		GLA (m^2)	$P = -18.40 \ln(x) + 142.28$	0.88	1.54 space/100 sq. m GFA
		Number of workers' vehicles	$P = -28.06 \ln(x) + 94.51$	0.70	1.07 space/worker's vehicle
Institutional office	Peak	Number of workers	$P = 0.48 * X - 0.57$	0.97	0.48 space/worker
		GFA (m^2)	$P = 0.025 * X - 2.18$	0.97	2.41 space/100 sq. m GFA
		GLA (m^2)	$P = 0.024 * X + 3.26$	0.95	2.50 space/100 sq. m GLA
		Number of workers' vehicles	$P = 1.03 * X - 7.17$	0.95	0.96 space/worker vehicle
	AM	Number of workers	$P = 0.478 * X - 5.269$	0.98	0.45 space/worker
		GFA (m^2)	$P = 0.025 * X - 7.082$	0.98	2.29 space/100 sq. m GFA
		GLA (m^2)	$P = 0.024 * X - 1.882$	0.98	2.37 space/100 sq. m GLA
		Number of workers' vehicles	$P = 15.502e^{0.012x}$	0.98	0.91 space/worker vehicle
	PM	Number of workers	$P = 0.486 * X - 5.449$	0.99	0.46 space/worker
		GFA (m^2)	$P = 0.025 * X - 7.057$	0.99	2.33 space/100 sq. m GFA
		GLA (m^2)	$P = 0.024 * X - 1.449$	0.97	2.41 space/100 sq. m GLA
		Number of workers' vehicles	$P = 1.045 * X - 12.121$	0.98	0.93 space/worker vehicle
Government office	Peak	Number of workers	–	–	0.33 space/worker
		GFA (m^2)	$P = 11.53 \ln(x) - 57.71$	0.61	1.68 space/100 sq. m GFA
		GLA (m^2)	$P = 10.62 \ln(x) - 49.92$	0.64	1.82 space/100 sq. m GLA
		Number of workers' vehicles	–	–	1.17 space/worker's vehicle
	AM	Number of workers	$P = 11.89 \ln(x) - 26.93$	0.65	0.31 space/worker
		GFA (m^2)	–	–	1.55 space/100 sq. m GFA
		GLA (m^2)	$P = 9.88 \ln(x) - 46.77$	0.64	1.69 space/100 sq. m GLA
		Number of workers' vehicles	$P = -0.312 * X_1 + 23.903$	0.78	0.92 space/worker's vehicle
	PM	Number of workers	–	–	0.31 space/worker
		GFA (m^2)	–	–	1.57 space/100 sq. m GFA
		GLA (m^2)	–	–	1.70 space/100 sq. m GLA
		Number of workers' vehicles	–	–	0.93 space/worker's vehicle

Table 8
Parking generation models/rates for retail land use.

Class	Independent variable (X)	Model	R^2	Rate
Supermarket retail	Number of workers	–	–	1.15 space/worker
	GFA (m^2)	–	–	2.08 space/100 sq. m GFA
	Number of workers vehicle	–	–	3.91 space/worker's vehicle
Strip retail	Number of workers	$P = 0.492 * X + 4.843$	0.68	0.82 space/worker
	GFA (m^2)	$P = 0.009 * X + 6.453$	0.75	2.22 space/100 sq. m GFA
	Number of workers vehicle	–	–	1.52 space/worker's vehicle

Verification tests were also performed for parking generation rates. In general, rates yielded higher difference between the observed and estimated parking demand values than the models for the studied land uses and their classes. In summary, the differences were: 0–47% for APH and DH residential uses, 0–100% for government office, and 14–27% for strip retail.

6. Comparison with local and international rates

As stated before, local parking requirements are not based on field studies and regional and international parking rates may not be appropriate for local use. As such, a comparison is made for the peak parking demand between the study results, local parking requirements, parking generation rates for Abu Dhabi, and the ITE parking generation rates for the similar land uses, as shown in Table 10.

The study results are somewhat different than local parking requirements. Although the peak parking demand for residential use is less than one parking space per occupied dwelling unit, it is well-understood that MoLG requires one space for each unit. The MoLG regulations do not differentiate between general office use and institutional office use in terms of parking requirement. The institutional office has higher parking demand than MoLG requirement since the nature of these offices

Table 9
Model verification results.

Period	Independent variable	Model	Sample no.	Estimated	Observed	Difference (%)
Residential DH						
AM	Number of Occupied DH Units	$P = 0.911 * X^{0.911}$	1	29	35	17
			2	33	37	11
	Number of Inhabitants	$P = 0.157 * X^{1.065}$	1	34	35	3
			2	40	37	−8
PM	Number of Inhabitants	$P = 16.781 * \ln(x) - 502.77$	1	35	47	26
			2	37	36	−3
General office						
Peak	GFA (sq. m)	$P = 11.53 \ln(x) - 57.71$	1	18	18	−6
			2	38	45	18
			3	6	6	0
	GLA (sq. m)	$P = 10.62 \ln(x) - 49.92$	1	21	18	−17
			2	38	45	16
AM	Number of workers	$P = 11.89 \ln(x) - 26.93$	1	19	18	−6
			2	35	45	22
	GLA (sq. m)	$P = 9.88 \ln(x) - 46.77$	1	19	18	−6
			2	35	45	22
	Number of workers vehicles	$P = -0.312 * X + 23.903$	1	18	18	0
			2	7	45	84
PM	GLA (sq. m)	$P = 0.289 * X^{0.608}$	1	17	14	−21
			2	43	43	0
Strip retail						
Peak	Number of workers	$P = 0.492 * X_1 + 4.843$	1	13	14	7
			2	9	9	0
			3	15	15	0
	GLA (sq. m)	$P = 0.009 * X_1 + 6.453$	1	11	14	21
			2	8	9	11
			3	15	15	0

Table 10
Comparison of peak parking generation/requirement rates with local and international rates.

Land use	Unit	Study results	MoLG requirement[a]	Abu Dhabi rate[b]	ITE rate[c]
Attached housing	Dwelling unit	0.95	1.00	0.71–0.80	1.38
Detached housing	Dwelling unit	0.93		0.84–0.93	1.83
Apartments	Dwelling unit	0.51		1.35–2.08	1.23
General office	100 m^2 GFA	1.57	1.43	2.24–3.26	3.05
Institutional office	100 m^2 GFA	2.41		–	3.05
Government office	100 m^2 GFA	1.68	2.00	1.98–3.93	4.47
Strip retail	100 m^2 GFA	2.22	2.00	2.54–3.05	NA
Supermarkets	100 m^2 GFA	2.08		2.24–7.53	4.07
Shopping center	100 m^2 GFA	2.25		3.33–5.00	2.75–4.05

[a] *Source:* (Palestinian) Ministry of Local Government (2011).
[b] *Source:* The Department of Transport of Abu Dhabi (2012). The range is for different cities within the Emirate.
[c] *Source:* ITE (2010).

is generally for upper class employees with relatively high vehicle ownership. On the other hand, government office requires less parking since the majority of government employees are low to middle-level income with relatively low car ownership. The study results showed that parking demand for commercial use is slightly higher than MoLG requirements.

For obvious reasons, the local parking demand is clearly lower than the Abu Dhabi and ITE demand rates as those target higher income communities with much higher car ownership rates than in Palestine. An exception is for attached and detached housing in Abu Dhabi where the rates are relatively close to the study results.

7. Conclusions and recommendations

Estimating parking Generation is important because it has major effects on development, design, planning, and management of real estate and road network. Palestine does not have complete and specialized documents that provide engineers and planners the necessary parking demand estimation for current and new developments. This research establishes the first step towards a comprehensive parking generation document. It also presents the parking demand for a country with an economy in transition.

The selected land uses in this study represent the main and predominated land uses in Palestine. The research covers the urban areas, outside the CBD, of all main cities in the West Bank.

Based on the previous data and analysis, the followings are the main conclusions of this research.

- Twenty-six sites of office land use, 23 sites of residential land use, and 24 sites of retail land use were surveyed and studied. The most predominant independent variables to estimate parking demand are number of dwelling units and number of inhabitants for residential land use; gross floor area, gross leasable area, and number of vehicles owned by workers are the predominant independent variables for office land use; and gross leasable area and number of workers are the predominant independent variables for retail land use.
- Simple regression analysis, which is the most common method to develop rates and models for parking generation, was used. Three periods of analysis were studied (AM, PM, and the peak of facility) during typical weekdays.
- Rates and models were developed for all land use types. Both good to poor models and rates were investigated. All land use classes' models and rates were built; however, with different reliability due to some statistical factors. Furthermore, the socioeconomic differences among cities have produced models with various statistical significance levels.
- For certain land uses, the sample size was small as these were the available facilities that satisfy the field survey criteria. This was the case for attached housing, general office, and institutional office classes. Therefore, caution should be taken when using the developed models or rates for these classes.
- In general, models are recommended to be used over rates. Models with coefficient of determination (R^2) greater than 0.5 are classified as fair to good models; confidence interval should not be less than 95% to get real information. In this research, it is recommended to use the model over the rate when R^2 is greater than 0.60.
- The produced models will have higher power when the size of the facility is within the range of data set of the models. Therefore, although the sample sizes were above the minimum and the recommended models achieved the targeted statistical significance, caution should be exerted when using the models for data outside the studied ranges. Furthermore, the models for the general and institutional office classes may be used with caution since their sample sizes were relatively small and there were large differences between parking demand estimates using the rates and the models.
- Verification of models and rates show that, in general, observed values are reasonably close to the estimated values produced; models showed higher verification results than rates. Few samples showed high differences (higher than 30%) between the estimated and observed values (1 out of 25 for models and 18 out 63 for rates).
- The output of this research was compared with the standard values for other countries, such as the Parking Generation by the Institute of Transportation Engineering (USA) and Trip Generation and Parking Rates Manual for Emirate of Abu Dhabi (UAE). It is found that the parking demands for the investigated land uses in Palestine had much lower rates.

The results of this research are valuable for local use and can be developed to be highly reliable for use in Palestine. The following points will enrich the study and open new opportunities for forthcoming researchers:

- The research covers only three types of land uses. As this is envisioned to be the core of the future "Palestinian Parking Generation Manual", similar studies should be conducted to include additional land uses and to cover Gaza Strip cities as well.
- This study was built based on available resources; for example, availability of sites, time, and budget. In addition, while preparing this study, there were many developments that were under construction that fulfill the study criteria. It is recommended to increase the reliability of the models developed in this research by increasing the sample size of each land use class.
- The outputs of this research are recommended to be adopted locally by government institutions (MoLG and municipalities) to improve the development and planning process in Palestine.

References

Al-Masaeid, H., Al-Omari, B., Al-Harahsheh, A., 1999. Vehicle parking demand for different land uses in Jordan. ITE J. 69 (5), 79–84.

Al-Sahili, K., 2010. Traffic Analysis and Simulation of Al-Ersal Center Project. Ramallah, Palestine.

Douglass, M., Abley, S., 2011. Trips and Parking Related to Land Use (Report No. 453), Retrieved from NZ Transport Agency Research. <http://www.nzta.govt.nz/resources/research/reports/453/>.

Garber, N., Hoel, L., 2010. Traffic and Highway Engineering. Cengage Learning, USA.

Green, S.B., Salkind, N.J., 2010. Using SPSS for Windows and Macintosh: Analyzing and Understanding Data, sixth ed. Prentice Hall Press, USA.

ITE, 2010. Parking Generation (Report No. IR-034C). ITE, Washington, D.C., Retrieved from <http://ecommerce.ite.org/IMIS/ItemDetail?iProductCode=IR-034C>.

McCourt, R., 2004. Parking Generation (Report No. IR-034B). ITE, Washington, D.C., Retrieved from <http://ecommerce.ite.org/IMIS/ItemDetail?iProductCode=IR-034B>.

Ministry of Local Government. 2011. Buildings System and Regulations for LGU's. Ramallah, Palestine. Retrieved from <http://www.molg.pna.ps/Laws.aspx?id=2>.

Ministry of Local Government of Palestine, 2015. GeoMOLG [Integrated Spatial Information System] Retrieved from <http://www.molg.pna.ps/>.

Montgomery, D., Runger, G., 2002. Applied Statistics and Probability for Engineers, third ed. John Wiley & Sons, Inc, USA.

Regidor, Regin, J., 2010. A Review of Trip and Parking Generation Rates in the Philippines. Philippine Eng. J. 27 (1).

Roads and Traffic Authority, 2002. Guide to Traffic Generating Developments. Sydney, Australia. Retrieved from <http://www.rms.nsw.gov.au/documents/projects/guide-to-generating-traffic-developments.pdf>.

Shacham, M., Brauner, N., Cutlip, M., 1996. Replacing graph paper with interactive software in modeling and analysis of experimental data. Comput. Appl. Eng. Educ. 4 (3), 241–251.

The Department of Transport of Abu Dhabi. 2012. Trip Generation and Parking Rates Manual for Emirate of Abu Dhabi. Abu Dhabi, UAE.