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Traffic Capacity at Entrances and Exits of Universities, Hospitals and Shopping Centers in Jordan

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Abstract

The main objective of this research was to develop models to estimate the capacity at parking lot entrances and exits (gates) for different land uses (universities, hospitals, and shopping centers) in Jordan, and to determine the influence of geometric and control factors on their capacities. Continuous queues were recorded at each gate. Also, geometric elements were measured for each gate including; number of lanes, gate width, speed hump height and width, and slope of the gate. Regression analysis was used to develop six gates models. At first, a general model was developed in which the data of all land uses and gate types were included. Then, three models were developed; one model for each land use. Finally, a model for each gate type (entrance or exit) was developed. The analysis indicated that the number of lanes and control method have the major significant effect on gate capacity. University gates have the largest traffic capacities among the three studied land uses. The hospitals gates come in the second place whereas the shopping centers gates come at last. This can be referred to the fact that the users of gates may be different from one land use to another. This research found that exits have more capacity than entrances because usually there is no control on exits, and automatic control could reduce the traffic capacity at entrances due to that more time is needed for checking and processing.

Keywords: Capacity, Gate, Entrance, Exit, Parking Lots, Land Use.

1. Introduction

Entrances and exits (gates) are important segments of the transportation system which separate external roadway networks from the internal facilities' roadways. Gates are considered the first elements for any land use, policy and regulation control entry and exit of vehicles. During the peak hours, some land uses such as parking lots of universities, hospitals, and shopping centers (malls) witness traffic congestion at their gates which may affect the traffic along the surrounding roadway networks. When arrivals rate exceeds the service rate of the gate, a queue will be generated causing traffic delays. So, it is important to design these gates with enough capacities, Al Shdifat [1].

Capacity is defined as the maximum number of vehicles that can pass a point on a roadway during a given period of time under the prevailing roadway, traffic, and control conditions, TRB [14]. Capacity in this research is expressed as vehicle per hour per lane (vphpl).

The proper design at the entrance and exit should prevent cars from queuing, because the queuing vehicles impede and disturb the traffic movement at the adjacent street. Selecting a proper number of lanes, proper gates width, and proper length of the storage lane (reservoir lane) will lead to a successful operation at the entrances and exits with the lowest number of traffic problems, Frantzeskakis [6]. Illustration of the gate's storage (reservoir) lane is shown in Fig. 1, and number of lanes and gate width are illustrated in Fig. 2.

Fig. 1. Illustration of Gate's Storage (Reservoir) Lane

When the arriving rate exceeds service rate at a specific entrance/exit, then an overflow situation will occur with a queue generated in front of this entrance, and when this queue extends to the adjacent road, it will cause some safety issues such as enforcing vehicles on the major street to stop surprisingly and reducing the operational capacity of adjacent roads, Crommelin [4]. On the other hand, extra number of lanes will cause inefficiency, additional financial burden, and confusion for drivers about which entrance/exit lane to use.

The entrance/exit location is recommended to be at mid-block far away from intersections to avoid conflict with traffic

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in the surrounding area, ITE [9]. If the parking lots contain a large number of vehicles, then it is recommended to use more than one gate to distribute the traffic at all surrounding streets equally, ITE [9]. The driveway or entrance area should be located such that there is adequate sight distance for all vehicles leaving the parking and vehicles entering the parking area, Waitakere City council [16].

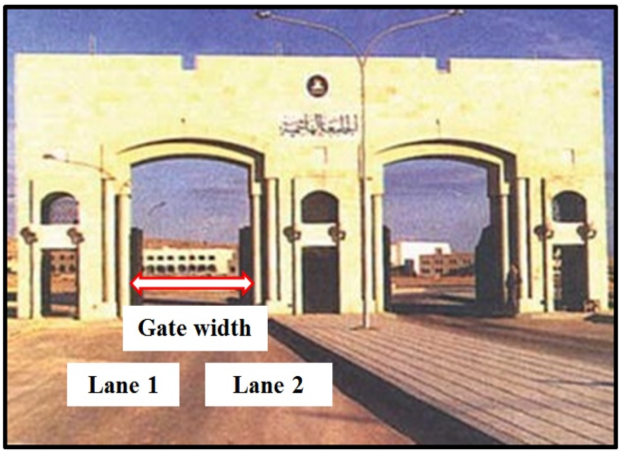

Fig. 2. Illustration of the Entrance/Exit Gate Width and Number of Lanes

Generally, traffic entrances/exits control can be divided into two major types; manual and automatic control systems, Al Shdifat [1]. Each type has its advantages and disadvantages. In the manual system, the human controls the process of vehicles entering to or leaving from the land use. The advantage of the manual system is that more capacity can be achieved, while on the other hand it has the disadvantages of more labor needs, less efficiency, and variable time needed for each vehicle. The Automatic control system is an automated system that controls the process at entrances/exits without human effect, Gujja and Wakta [7]. The advantages of automatic control system include more efficiency, safety, and reliability, Upchurch [15]. On the other hand, the major disadvantage of automatic system is that less capacity may be achieved as compared with the manual system.

Usually, in the manual control systems, the long queue results in shorter checking time at the entrance or exit, while when few vehicles are available then they usually have more processing and checking time especially at entrances; due to the fact that drivers tend to ask more questions about the exact locations of their specific destinations and the security men also tend to spend more time in inspection.

In this research, three types of land uses will be investigated; universities, hospitals, and shopping centers (malls). Each type has different traffic characteristic and peak periods.

The universities gates have two major peak periods; one is in the morning and the other is in the evening depending on work schedule at the university itself, which could make congestion during these times. For the rest of the day, the number of vehicles that are expected to enter or exit from the gate is very little. The hospitals gates have two major peak periods similar to universities; one is in the morning and the other is in the evening. For the rest of the day, the vehicles entering and leaving the gate are slightly more than the universities gates. The shopping centers gates don't have a clear peak hour, but most vehicles cross their gates when people are shopping in the evening.

2. Literature Review

Hintersteiner [8] has specified the factors that cause delay when a vehicle enters or leaves a parking lot as related to the lack of easy entry which makes long queues of vehicles on the adjacent streets. He used the planning method to design the required number of portals. This method involves determining the maximum number of vehicles that would be generated by the entire complex and then dividing that number by the surge capacity for the type of gate control system selected, to yield the number of portals required during the peak hours. He found that for a driveway without control in a self-parking facility, the typical capacity for a lane ranges between 300 and 600 vehicles per hour (vph). The followings are some of his study's findings: the recommended design hour volume per lane is 400 vph., the recommended design volumes for a portal with a gate control, for free entering and leaving gate with only vehicles detectors, and for lift garage door are 300 vph., 360 vph., and 72 vph., respectively.

Upchurch [15] has studied the capacity of entrance stations as determined from data collected at Arches National Park in Utah and compared it with data collected at Grand Canyon National Park. He noticed that if automated lanes are used, they increase the entrance station capacity. Based on data collected from Arches National Park the entrance capacity was about 112 vph.

O'Flaherty [13] has suggested that the capacity of an entrance of a car parking is determined by the angle of entry, the freedom of internal circulation, and the type of control. If the users are familiar with the park and know the car park operation well, the entrance capacity is usually increased. In general, as the entrance width and radius is increased, it becomes easier for the driver to access the car parking.

Maršanić et al. [10] applied queuing theory to determine the optimal number of servers (ramps) in closed parking systems (lots), and they determined the number of parking spaces and the required parking area capacity.

Australia/New Zealand standards [3] stated that number of entry and exit lanes required in large car parking lot will depend on the total number of peak hour vehicle movements, proposed number of entry/exit location, vehicular capacity of lanes at entry/exit point, and any additional lane needed to meet capacity requirements at access driveway/frontage road intersection. Vehicular capacities at entry points were estimated at free flow as 600 veh/hr/lane, at the card readers as 400 veh/hr/lane, at the automatic ticket issue gate as 300 veh/hr/lane, and at the manual controlled gate as 250 veh/hr/lane. Vehicular capacities at exit points, on the other hand, were estimated at free flow as 600 veh/hr/lane, at automatic ticket as 300 veh/hr/lane, and at cashier controlled as 200-250 veh/hr/lane depending on the parking fee structure.

Ellson [5] suggested that capacity of an entrance depends upon the time period that each driver waits before the barrier arm lifts. The author pointed out that this capacity varies according to the purpose of the barrier (to ensure one-way flow, to count, to ensure the payment of fees or the issue of tickets). The author also stated that the capacity varies with the angle of storage lane with major street, the radius of curvature of the storage lane and its gradient, and to the position of the car relative to the coin machine, ticket machine, token machine and position of the detectors and that serves the waiting time for the driver. Some of the research findings include the followings: the capacity for take ticket type generally lies between 350 veh/h (when there is a tight left-hand turn at the entrance) and about 500 veh/h (when the approach is from the right or it straight line in approach). When the control layout mimicked in laboratory ground, the obtained results were 350-450 veh/hr for tight left-hand turn and take a ticket, 650-670 veh/hr for straight-approach and take a ticket, and 575-970 veh/hr for a tight left-hand turn only (no ticket taken).

When the car is beyond the exit barriers, the driver will wait for a gap in the frontage road, and as a result of this, the vehicles will wait for time that will exceed the stopped-time and move-up time of following vehicles and this will lead to queueing vehicles at exit, Ellson [5]. An important criterion of garage design is that a sufficient storage should be provided between the curb-line and exit barrier. So, collection fees or control procedures will not be affected by queuing vehicles, Ellson [5].

Maryland State Highway Access Manual [11] presents a standard gate design for industrial and commercial sites. The manual divides the entrance into many types depending on physical characteristics, functions, and traffic conditions. These types include: commercial two-way entrances, commercial one-way entrances, commercial right-in/right-out entrances, depressed curb entrances, and monumental entrances. The manual states that the width of the two-way entrance should not exceed 10 m and not be less than 7.5 m. The width for a one-way entrance, on the other hand, should not exceed 6 m and not be less than 5 m. For two way entrances, the angle of connection (measured between the centerline of street and the centerline of the entrance) must be between 70 and 110 degrees. For one-way entrances, the angle is recommended to be between 45 and 90 degrees, and if the frontage street is curved the tangent is considered for measuring the angle. For the vertical layout, the manual states that the grade of industrial and commercial site gates should be as flat as possible, the maximum grade allowed is 3% for general conditions, but with a low traffic inbound and outbound the site, the grade is allowed up to 6%. For connection depth/reservoir lane/throat length, the manual states that adequate storage lane length should be constructed to prevent vehicle queue to the frontage road. It is measured from the street edge to first on-site intersection.

3. Data Types and Collection

Field data were collected from selected gates on some universities, hospitals, and shopping centers in Jordan, during the summer of 2015. For the data to be representative, they were collected through video recording during peak periods of entering and leaving, at entrances in the morning peak and at exits in the evening peak, without any interruptions or unusual conditions. The collected data included the presence of control method (automatic control or manual control), land slope (level, up, or down slope), and the land type being public or private. The queue time and number of vehicles at each queue were recorded, Al Shdifat [1].

Field surveys were performed to measure the width of the gate, and length of storage lane (queue lane) in front and behind of each gate. If a speed hump is present at the gate, the width and height of the speed hump were also measured.

The capacity values at 31 gates in Jordan were obtained by measuring the saturation headway at every gate. The saturation headway for each gate was obtained by recording queues of vehicles, with a minimum queue length of three vehicles. For each queue, the "queue time" was recorded; the queue time is the time extending from when the front of the first vehicle passes the gate line until the front of the last vehicle passes the same line. Then, the saturation headway (S) was calculated by dividing the queue time by the number of vehicles in the queue excluding the first vehicle, Eq. (1). This procedure was repeated for at least 20 queues at each gate. The capacity for vehicles per hour was calculated by dividing 3600 by the saturation headway, Eq. (2). The weighted average was calculated to represent the capacity at each gate Al-Omari and Al-Masaeid [2].

S (Sec) = Queue Time (Sec) ∕ [Number of Vehicles at Each Queue-1] (1)

Capacity (Veh/hr/Lane) = 3600∕(S (Sec)) Eq. (2)

4. Models Development

Regression analysis was conducted to develop six capacity models at gates. First, a general model was developed for all data, all types of land uses, and all gate types. Other three models were developed based on the type of land use; university gate capacity model, hospital gate capacity model, and shopping center gate capacity model. The last two models were developed for the type of gate; entrance capacity model and exit capacity model.

The data were analyzed using the SPSS software to identify the relationship between gates capacities and their influencing variables and to develop gate capacity models for different land uses and for different gate types.

4.1 Development of General Gate Capacity Model

The data used in the general model consisted of 1240 queue observations in order to determine 62 capacities observations from 31 gates. The stepwise regression analysis was conducted to estimate the capacity at gates as a function of the number of lanes, if the land-use is university or not, hospital or not, if automatic control is used at gate or not, and if control exists at gates or not.

Multiple regression analysis was made to develop the general gate capacity model. The model was developed through a stepwise regression analysis. Based on data analysis, the following model was obtained:

$$C_{General} = 326.626\ L + 274.426\ X_{uni} + 116.484\ Z_{no-control} - 304.418\ Z_{automatic} + 129.911\ X_{hos} \quad \text{.... Eq. (3)}$$

Where:

$C_{General}$ = capacity of gate based on all types of land uses and all types of control (vphpl), L = number of lanes, X_{uni} = 1 if land use is University, 0 otherwise, $Z_{no-control}$ = 1 if no control in gate, 0 otherwise, $Z_{automatic}$ = 1 if the control type is automatic, 0 otherwise, X_{hos} = 1 if land use is hospital, 0 otherwise.

Table 1 shows the statistical characteristics of the general model and indicates that all independent variables are significant at 95% confidence intervals. The final model was statistically significant with $R^2_{adjusted}$ (adjusted coefficient of multiple determinations) = 0.959, with high level of significance (alpha = 0.000). It should be noted that the constant term in the general model is not significant.

Table 1. Statistical Characteristics of General model

Regression Parameter Estimates

Model Parameter	Unstandardized Coefficients		Standardized Coefficients	T test	Sig.
	B	Std. Error	Beta		
L	326.629	27.645	0.649	11.815	0.000
X_{uni}	274.426	44.619	0.237	6.150	0.000
$Z_{no\text{-}control}$	116.484	41.639	0.153	2.797	0.007
$Z_{automatic}$	304.418-	73.571	-0.118-	-4.138-	0.000
X_{hos}	129.911	39.986	0.112	3.249	0.002

Analysis of Variance

	Sum of Squares	Degree of Freedom	Mean Square	F test	Significance
Regression	25815365.392	5	5163073.078	288.714	0.000
Residual	1001446.608	56	17882.975		
Total	26816812.000	61			
$R^2_{adjusted}$ = 0.959					

Fig. 3 proves that there are no outlier observations. The figure shows that none of the residual values is greater than are the standard deviation multiplied by 3, Neter and Wasserman [12]. The scatter relationship in Fig. 3 between the residuals and the predicted values also shows that the residuals are randomly distributed and have the same range width in each predicted value. So, the constant variance assumptions were achieved.

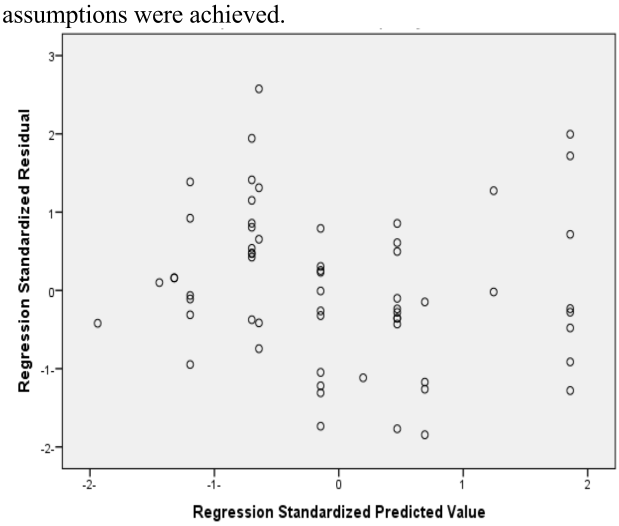

Fig. 3. Scatter Plot of Predicted Value versus Residuals for General Capacity Model

Fig. 4 presents the normal scores versus residuals. Since the plot shows an approximately straight line, so the population can be assumed as normally distributed, Neter and Wasserman [12]. Thus, it can be conducted that there is no need for any transformation of variables and no remedial actions are required.

It can be concluded from the general model (Eq. 3) that as the number of lanes (L) increases the capacity of gates (vehicle per hour per lane) also increases. This is because more lanes will give the vehicles more freedom to maneuver. Regarding the second factor (X_{uni}), the gates at universities accommodate more vehicles per hour than other land use gates, because all the queuing vehicles recorded had permit stickers to enter the university while the manual gate is open without any obstruction of any control. This trend is valid for all the studied gates except for one gate at Zarqa University at which automatic controls were used to control the entering and exiting movement of vehicles.

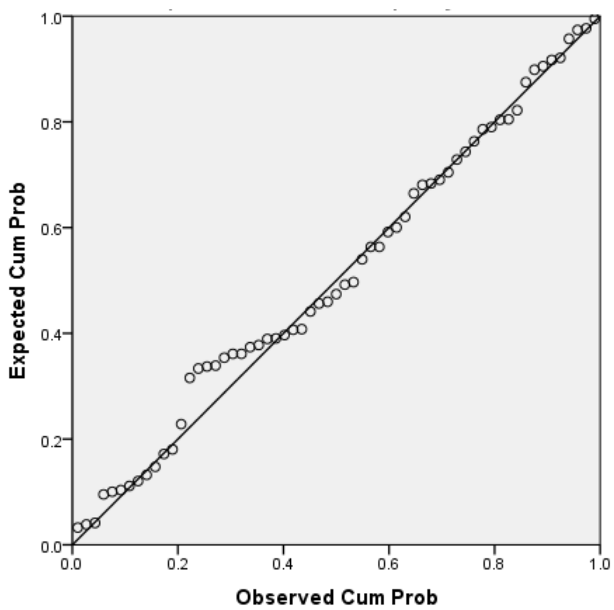

Fig. 4. Normal Plot for General Model

In Eq. (3), the third factor ($Z_{no\text{-}control}$) indicates the existence or non-existence of gate control. The model clearly indicates that if no control exists, the gate capacity will increase and the vehicles spend less time at the gate. The fourth factor that affected gate capacity is the existence or non-existence of the automatic control ($Z_{automatic}$) significantly decreases gate capacity, because more time is needed for every single vehicle to get the permission to enter or leave the gate, and this control type is not widely used in Jordan.

For the last factor that affected the general gate capacity model (X_{hos}), the gates at hospitals accommodate less vehicles per hour than university gates, but more than shopping centers gates, because less controls are applied at hospitals gates compared with controls applied at shopping centers gate, in other words, less time is required for single vehicles to go through the hospital gate compare with time required for single vehicle to go through shopping centers gate, Al Shdifat [1].

4.2 Development of Land-use Gate Capacity Model

Multiple regression analysis was carried out to develop one gate capacity model for each one of the different studied land uses. These land uses are the Universities, Hospitals, and Shopping Centers. Each land use has its own characteristics which may be different from other land uses, due to variations in work schedules, scopes, and gate users among these land uses. Based on the data collected from the three land uses considered in this study, the following three models were obtained.

4.2.1 Universities Model

The data used in the university model consisted of 400 queue observations to determine 20 capacity observations from 10 university gates. Stepwise regression analysis was conducted to estimate the capacity at gates as a function of number of lanes (L), and in the case of existence or non-existence of automatic control at the gate ($Z_{automatic}$). An exponential relationship was obtained as shown in Eq. (4).

$$C_{Uni} = 451 + e^{0.452\,L} + e^{-0.756\,Z_{automatic}} \quad (4)$$

Where:
C_{Uni} = Capacity for university gate (vphpl), L = number of lanes, $Z_{automatic}$ = 1 if the control type is automatic, 0 otherwise.
With $R^2_{adjusted} = 0.855$, the regression model and all independent variables were significant at 95% confidence interval as shown in Table 2.

Table 2. Statistical Characteristics of Land Use Models

	Sum of Squares	Degree of Freedom	Mean Square	F test	Significance
Analysis of Variance (Universities Model)					
Regression	2.408	2	1.204	56.825	0.000
Residual	0.360	17	0.021		
Total	2.768	19			
$R^2_{adjusted}$ = 0.855					
Analysis of Variance (Hospitals Model)					
	Sum of Squares	Degree of Freedom	Mean Square	F test	Significance
Regression	6472943.042	2	3236471.521	201.147	0.000
Residual	289620.958	18	16090.053		
Total	6762564.000	20			
$R^2_{adjusted}$ = 0.952					
Analysis of Variance (Shopping Centers Model)					
	Sum of Squares	Degree of Freedom	Mean Square	F test	Significance
Regression	184937.357	1	184937.357	18.100	0.000
Residual	194137.786	19	10217.778		
Total	379075.143	20			
$R^2_{adjusted}$ = 0.461					

4.2.2 Hospitals Model

The data used in hospital model consisted of 400 queue observations to investigate 20 capacity observations from 10 hospital gates. Again, stepwise regression analysis was conducted to estimate the capacity at gates as a function of number of lanes (L), in the case of existence or non-existence of automatic control at the gate ($Z_{automatic}$). Eq. (5) gives the resulted linear hospitals capacity model.

$$C_{Hos} = 516.458\,L - 327.458\,Z\,automatic \quad (5)$$

Where:
C_{Hos} = Capacity for hospital gate (vphpl), L = number of lanes, $Z_{automatic}$ = 1 if the control type is automatic, 0 otherwise.
With $R^2_{adjusted} = 0.952$, the regression model and all independent variables were significant at 95% confidence interval (Table 2).

4.2.3 Shopping Centers (Malls) Model

The data used in shopping centers model consisted of 420 queue observation to determine 21 capacity observations from 11 shopping centers gate. Stepwise regression analysis was conducted to estimate the capacity at gates as a function of manual control presence or non-presence (Z_{manual}). The developed linear shopping centers capacity model is given by Eq. (6).

$$C_{Mall} = 567.786 - 199.071\,Z_{manual} \quad (6)$$

Where:
C_{Mall} = Capacity for shopping centers (malls) gate (vphpl), Z_{manual} = 1 if the control type is manual, 0 otherwise.
With $R^2_{adjusted} = 0.461$, the regression model and all independent variables were significant at 95% confidence interval Table 2.

4.3 Development of Gate Types Capacity Model

Multiple regression analysis was carried out to develop gate capacity model for entrance gates and exit gates separately.
Generally, entrances capacities are less than exits capacities. One reason for this is the time needed to check entry permits when entering the gate. Another reason is that employees are usually more careful to get to work on time in the morning (entering) than in leaving (exiting) in the evening. This general trend is clearly shown in Fig. 5 where most of the studied gates had less capacities at entrances (morning) than at exits (evening). Using the data from each gate type, two models were obtained; entrance model and exit model.

4.3.1 Entrance Model

The data used in entrances model consisted of 660 queue observations to determine 33 capacities observations from 33 entrances. Stepwise regression analysis was conducted to estimate the capacity at entrances as a function of number of lanes (L), control use or not ($Z_{no\text{-}control}$), and whether the entrance has public or private ownership ($Z_{public\_private}$). Eq. (7)

introduces the developed model.

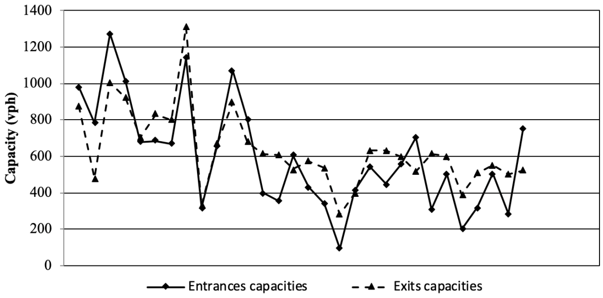

Fig. 5. Relationship between Entrance and Exit Capacities for the Studied Gates

In this model, a new parameter was introduced ($Z_{public\_private}$). This is due to a difference in control regulations between public and private land uses. In this model, a less capacity is expected when the land use is private due to more control regulations.

$$C_{Entrance} = 335.56\ L + 229.117\ Z_{no-control} + 148.722\ Z_{public\_private} \quad (7)$$

Where:

$C_{Entrance}$ = Capacity for entrance gate type (vphpl), L = number of lanes, $Z_{no\text{-}control}$ = 1 if no control in gate, 0 otherwise, $Z_{public\_private}$ = 1 if public land use, 0 if private land use.

With $R^2_{adjusted} = 0.949$, the regression model and all independent variables were significant at 95% confidence interval Table 3.

Table 3. Statistical Characteristics of Gate Types Models

Analysis of Variance (Entrance Model)					
	Sum of Squares	**Degree of Freedom**	**Mean Square**	**F test**	**Significance**
Regression	13229723.213	3	4409907.738	206.111	0.000
Residual	641872.787	30	21395.760		
Total	13871596.000	33			
$R^2_{adjusted}$ = 0.949					
Analysis of Variance (Exit Model)					
	Sum of Squares	**Degree of Freedom**	**Mean Square**	**F test**	**Significance**
Regression	749356.522	2	374678.261	19.411	0.000
Residual	482570.192	25	19302.808		
Total	1231926.714	27			
$R^2_{adjusted}$ = 0.608					

4.3.2 Exit Model

The data used in exits model consisted of 560 queue observations to determine 28 capacities observations from 28 entrances. Stepwise regression analysis was conducted to estimate the capacity at entrances as a function of number of lanes (L), and whether the exit belongs to a university gate or not (X_{uni}). The developed model is introduced in Eq. (8).

$$C_{Exit} = 317.596 + 246.71\ X_{uni} + 201.21\ L \quad (8)$$

Where:

C_{Exit} = Capacity for exit gate (vphpl), X_{uni} = 1 if land use is University, 0 otherwise, L = number of lanes

With $R^2_{adjusted} = 0.608$, the regression model and all independent variables were significant at 95% confidence interval Table 3.

5. Results and Discussion

In this study, six gate capacity models were developed using an empirical approach. The development of the models was achieved in three steps. In the first step, a general gate capacity model ($C_{General}$) was developed for all types of land uses and gate types. In the second step, three capacity models were developed for the three studied land used (C_{Uni}, C_{Hos}, and C_{Mall}). Finally, in the third step, two capacity models were developed for the entrance ($C_{Entrance}$) and exit (C_{Exit}) gate types.

The relationship between the capacity and affecting factors had a linear form without any required transformation, and this was true for all developed models except for the university model. The scatter plot between residuals and predicted values for the university model as seen in Fig. 6 shows a nonlinear relationship (increased pattern) and therefore the exponential transformation was used. The new scatter plot for the same model after transformation is shown in Fig. 7.

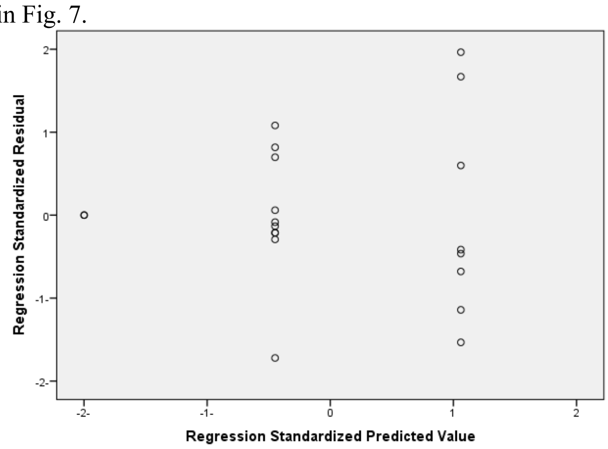

Fig. 6. Scatter Plot of Predicted Value versus Residuals for University Capacity Model

The first step was to develop the general model that estimated the capacity in all types of land uses and all types of gates combined as a function of five parameters. The first parameter is the number of lanes; where the general model showed that as the number of lanes increases, the capacity of gates increases. The reason can be attributed to the fact that adding more lanes will give the vehicles more freedom to maneuver. The second significant factor was the gate being a university gate or not. University gates accommodate more vehicles per hour than other land uses gates; this is because the majority of the queuing vehicles have the entrance permit that enables them to enter the university without obstruction of any control, except for one gate at Zarqa University where automatic control was used for the entering and exiting vehicles.

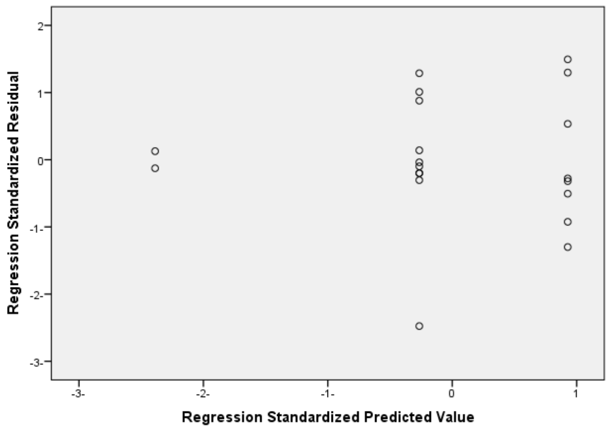

Fig. 7. Scatter Plot of Predicted Value versus Residuals for University Model (after transformation)

The third factor found significant in the general model was the gate being a hospital gate or not. Hospitals gates accommodate fewer vehicles per hour than university gates but more than shopping centers gates; this is because less control is applied at hospitals gates compared with the controls applied at shopping centers gates. In other words, less time is required for a single vehicle to go through a hospital gate compared with time required for a single vehicle to go through a shopping center gate. The fourth factor included in the general model had to do with the existence or absence of automatic control. The existence of the automatic control, which is not widely used in Jordan, significantly decreases gate capacity. The last factor that is significant in the general gate capacity model had to do with the gates being controlled or non-controlled gates. As the model clearly shows, if no control exists, then the vehicles spend less time at the gate, and the gate capacity increases.

In the second step, a gate capacity model was developed for each land use. A university gate capacity model was developed as a function of number of lanes and automatic control existence. Then, a hospital gate capacity model was developed based on of number of lanes and automatic control existence. And finally, a shopping center capacity model was developed based on only one factor (manual control) because most shopping centers' parking lots are controlled by human personnel with gates that have limited variation in number of lanes and gate width. It should be noted that the adjusted coefficient of multiple determinations ($R^2_{adjusted} = 0.488$) for this model was very small compared with other models. This may be due to the effect of human control which is characterized by a high variation in checking time, in addition to the fact that shopping centers have no specific peak hours like universities or hospitals.

In the last step, a gate capacity model was developed for each type of gate; one was developed for the entrance and the other was developed for exit. Different conditions exist between entering and leaving a gate. The reasons behind these different conditions are the presence of control at gate entrances, some drivers may ask some questions while entering the gates and hence spending more time at entrances, and the drivers are more careful about getting to work on time in the morning (entering) than when leaving (exiting). This led to less capacity at entrances compared with exits.

The entrance model is affected by number of lanes, control, and land use ownership. The ownership factor has a significant effect on the entrance model only. This is because, generally, in the private land uses there is more concern about security and vehicles which are authorized to enter and leave the land. The exit model is found to be affected by number of lanes and whether the gate is a university gate or not.

6. Conclusions

Gate geometric variables, including number of lanes, have the greatest effect on capacity, as noted in all developed models. More lanes lead to more capacity at gate, because more lanes give vehicles more freedom to maneuver. If there are more than one lane used at gate, the vehicles with permits enter gate take exclusive lane, so it will not be affected by other vehicles waiting to get permission to enter, which leads to more checking time.

University gates have the greatest capacity because in this research study only vehicles with permits to enter university were taken into consideration. The vehicles without permits are rare at university gates and will not form queues, and therefore they were excluded in this study.

Shopping centers gates have the lowest capacity, because all entering vehicles must be checked, and because all shopping centers gate are manually controlled.

Exit gates have more capacity than entrance gates, because most gate control are found at the entrance and because more vehicles enter the gate at entrance peak hour in the morning compared with exiting vehicles in the evening peak hour. More vehicles lead to more delay.

Gates with no control have the highest capacity because no delay is caused by the checking process.

Automatic control gates have less capacity than manual gates, due to more process needed with automatic controls.

The adjusted coefficient of multiple determinations ($R^2_{adjusted}$) for shopping centers model is small compared with that of other models, so it is recommended to do further research on shopping centers' gates.

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