ESTIMATION OF SHOULDER LANE UTILIZATION ON EXPRESSWAY MIDBLOCK SECTION

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Abstract: During the peak hour, drivers are occasionally allowed to use the shoulder lane on the Kanjanapisek Expressway to provide additional space and reduce travel delay. Based on the observation, we found a significant number of vehicles regularly used the shoulder lane both during the peak and off-peak period. Concentrate on midblock section, we found the use of shoulder lane during the free flow traffic condition. The consequence of inconsistent lane utilization on midblock section affects the stability of traffic flow and creates a bottleneck on the expressway. This study aimed to investigate the characteristic of shoulder lane utilization behavior, identified significant parameters affecting shoulder lane utilization behavior and compared the empirical data with simple linear regression and sigmoid function. In this study, the empirical data of 5 expressway midblock sections on the Kanjanapisek Expressway was chosen for study area. Traffic stream data collections were gathered from image processing traffic detection system. The result indicated that the shoulder lane utilization behavior has unique characteristic in different flow condition. The most influenced factors that contributes to shoulder lane utilization was the total density. Linear and sigmoid function were compared to establish relationship between the influenced factor and the shoulder lane utilization. In term of modelling, the sigmoid function provided good estimates of shoulder lane utilization on expressway midblock section of the Kanjanapisek Expressway. These results should contribute to a better understanding of discretionary lane selection behavior.

Keywords: shoulder lane utilization, expressway, midblock, discretionary lane selection.

1. Background

According to a policy for geometric design of highway and street (AASHTO, 2011) recommended that the shoulder lane in expressway should be designed wider than the shoulder of a typical urban road. It should be approximately 2.40-3.00 meters wide depending on the number of regular lane. Following the left-handed driving rule in Thailand, the shoulder lane on expressway is located on most left lane close to the edge barrier and the lane width is 3.00 meters which is narrower than a regular lane (3.60 meters). In term of traffic control and regulation, the shoulder lane was typically expected to be used as (1) safety clearance in case of necessary to avoid collisions, obstructions or roadblocks; (2) refugee area for emergency or accident victims; and (3) emergency access such as ambulance, police car, rescue vehicle in congested condition.

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The observation of expressway network in the Bangkok Metropolitan and vicinity areas which are operated by the Expressway Authority of Thailand (EXAT) found a significant number of vehicles using the shoulder lane as a regular lane especially during the rush hour. The most common location for shoulder lane use on expressways were both the ramp junction and the midblock section. Although the using of shoulder lane both for travelling or overtaking tend to increase capacity of the expressway especially on demanded period but it is more likely to create bottleneck and accident. Obviously, lane width of the shoulder lane was usually narrower than the regular lane which potentially to collided with the barrier along the expressway or the vehicle in the adjacent lanes. Furthermore, shoulder lane use will obstruct the rescue operation in case of emergency and violated to the Thai Traffic law regulation under the Land Traffic Act (Royal Thai Police Department, 1979) which stated that the shoulder lane has been preserved as extra space to escape from ordinary traffic and provide an emergency access for rescue operation and definitely its prohibited for using as regular traffic lane.

On the other hand, the common approach of traffic management to alleviate the recurrent traffic congestion which primarily cause by the exceed demand over capacity of the road network consist of; (1) the construction or expansion of infrastructure to increase the capacity (Mirshani et al., 2007) and (2) the management of existing infrastructure to maximum efficiency. In term of application, we found the widely use of shoulder lane as a temporary lane during the peak period in the western counties (Duret et al., 2012). Several studies stated that this kind of application gained more benefit to road network by reducing congested duration and accident rate. It is more cost effective compared to the construction of the new infrastructure (Berger and Maurer, 1999), (Kellermann, 2000), (Nezamuddin, 2011).

Even though the success and benefits of temporary shoulder use in the several western countries are highlighted but the application of such system on expressway network need to essentially consider on many factors. Especially, when we are dealing with various driving behavior and the distinct of laws regulation, the application of shoulder lane as extra space on the Expressways in Thailand is likely to produce the contrasting results. This study aims to investigate the characteristic of shoulder lane utilization behavior, identified significant parameter effect to shoulder lane utilization behavior and compared the empirical data with simple linear regression and sigmoid function on the Kanjanapisek Expressway. The result will contribute to a better understanding of discretionary lane change behavior of vehicle on multilane expressway in Thailand.

2. Literature Review

In term of lane distribution characteristic; Daganzo assumed that there were 2 types of drivers called “rabbit” and “slug”, where “rabbit” was the driver in fast lane and “slug” was the driver in slow lane (Daganzo, 2002a), (Daganzo, 2002b). In case of expressway or freeway, several researches were done on the multilane expressway, (Amin and Bank, 2005) studied lane utilization characteristics of the freeway in San Diego and explored that the flow rate on median lane always greater than the other lanes in the same direction both under congested and uncongested conditions. (Pompigna and Rupi, 2017) developed the lane utilization model and
capacity on 3 lanes freeway section in Italy. The result indicated that the driver possibly moved to inner lane once the flow rate increased and the unbalance lane utilization caused by driving regulation and poor lane discipline. In case of capacity analysis, the result shown that the estimated capacity of test section was lower than ideal value as given in the Highway Capacity Manual (HCM, 2010).

(Gunay, 2004) studied the lane utilization in Turkish highway indicated that one of reason which created the imbalance lane utilization was the road geometry; the poor road surface, poorly maintenance and the unclear of lane marking or existed of studs on lane lines. This kind of situation will potentially lead the vehicle to losing of safety and it also made trouble to the traffic management. (Xiao et al., 2014) studied of the lane utilization on long continuous highway and concluded that the lane utilization influenced by highway geometry and revealed that the straight section of highway likely gained high utilization on median lane and highly on-ramp volume probably increased the lane utilization on shoulder lane. (Knoop et al., 2010) studied the lane utilization of freeway and indicated that lane utilization will be fluctuated on the ramp area which contrasting with the output from (Amin and Bank, 2005).

The driving environment was one of the influenced factor to the lane utilization, (Hollis and Evan, 1976), (Turner, 1983), (Fwa and Li, 1995) concluded that one of major factor affecting lane utilization was the volume of the trucks in road network. (Gunay and Erdemir, 2011) found that the vehicles prefer to stay behind or lead ahead based on flow rate and density when headway of vehicle close to leading vehicle, they were forced to move side by side. (Bangarraju et al., 2016) explored the none-lane based behavior of traffic considering the laterale behavior, effect of traffic composition and headway behavior of vehicle and the outcome revealed that the density, flow rate and mean speed of traffic stream contributed to lane change maneuver and influenced to lane change duration. Nonetheless, the distinct regulation and culture between countries also influenced the lane utilization; (Wu, 2006) studied on 2 lanes and 3 lanes highways revealed that lane utilization was lower capacity than middle lane or medium lane. (Carter et al., 1999) demonstrated the variation of lane utilization by considering the lane discipline rules, amount of heavy vehicle and the location of on and off ramps. The result showed that the lane utilization relates to the lane location, capacity, speed and density. The distinct driving attitude also created the imbalance lane utilization, (Gunay, 2007) developed the car following model based on lateral distance between vehicle and indicated that movement of following vehicle was formulated with the off-centre effects from leading vehicle. (Choudhury et al., 2008) presented the cooperate lane changing model which allows drivers to merge in mandatory and discretionary situation and the important parameters of the model was the vehicle trajectory data.
significantly different between Germany and North America.

The lane utilization or lane flow distribution model has been proposed by different authors. (Wu, 2009) predicted the lane utilization on multilane freeway in Germany by modifying the lane-change probability model proposed by (Heidamann, 1994), (Okura and Somasundaraswaran, 1996) based on exponential regression model and focusing on capacity. (Knoop et al., 2010) explained that the lane utilization as a function of traffic density. (Lee and Park, 2010) developed the lane utilization model on basic freeway segment in Virginia by applying a series of polynomial. (Duret et al., 2012) studied the lane utilization on multilane freeway in France and identified linear relationship with total flow. (Samoili et al., 2013) investigated the variation of flow and density in San Diego, California and explored the dynamic relationship with nonparametric locally weighted regression as a function of total density. (Lueanpech and Rongviriyapanich, 2017) developed a nonlinear regression model using a Generalized Additive Model (GAM) to estimate the shoulder lane utilization on expressway in Thailand and indicated that the influence factor affects to shoulder lane utilization include speed different between adjacent lane and percentage of heavy vehicle.

The shoulder lane is a part of road design and typically expected for clearance zone and emergency issues. Many cases of traffic mitigation usually done by providing extra space for vehicle and it also effected to the lane utilization. (Moriyama et al., 2011) studied effect on lane utilization and capacity in case of adding an auxiliary lane to the climbing section on the Chuo Expressway. It was found that during the test date the utilization on adding auxiliary lane was significantly increased, slightly increased on traffic capacity and potentially alleviated the traffic congestion.

This study focuses on the shoulder lane utilization behavior on expressway midblock section which seem to be discrete circumstances. The modeling of shoulder lane utilization based on simple linear regression and sigmoid function were constructed and compared with the empirical data of 5 expressway midblock sections on the Kanjanapisek Expressway.

3. Methodology

3.1. Case Study Setup

The Kanjanapisek Expressway was chosen as study area. It is located on the southern part of the Bangkok Metropolitan Outer Ring Road where 46 microwave traffic detectors and 10 image processing detectors have been installed. It is an elevated 6-lane expressway with a total length of 22.5 kilometers. Since November 15, 2007, the Kanjanapisek Expressway was opened as a toll road with a distance-based toll collection system. Fig. 1 illustrated the Kanjanapisek Expressway and detector location. According to the statistics from fiscal year 2017, average daily traffic on the Kanjanapisek Expressway was 257,935 veh/day in both directions comprising 87.3% passenger car, 8.2% of medium trucks and 4.5% of heavy trucks (Expressway Authority of Thailand, 2017).
3.2 Traffic Data Collection

The traffic data collection for this research collected by 10 image processing traffic detectors which are installed on gantry structure 6 meters above the expressway surface. The spacing of each image processing traffic detector system (IDS) approximately every 5 kilometers located at the midblock section and typically captured the traffic measurement on the shoulder lane, lane 1 (left most lane), lane 2 (middle lane) and lane 3 (right most lane) Fig. 2 illustrated the configuration of image processing traffic detectors. The seven days data from June 11-17 in 2017 were downloaded from the EXAT ITS database system. In pursuance to describe the dynamics of traffic conditions, the dataset in this study were aggregated in 5 minutes intervals.
3.3. Lane Utilization

The expression of lane utilization could be indicated as the distribution of macroscopic variable of traffic to each lane on multilane expressway. This idea was approached to lane usage, lane split and lane ratio. This study considered the utilization based on total flow rate ($q_t$) especially flow rate on shoulder lane ($q_s$), meanwhile the shoulder lane utilization (SLU) was the ratio between flow rate value on shoulder lane and the total flow rate of the freeway section. The equation was used to calculate the shoulder lane utilization in this study as below, Eq. (1):

$$SLU = \frac{q_s}{q_t}$$  \hspace{1cm} (1)

Where $q_s$ is the flow rate on shoulder lane (pcu/hr) and $q_t$ is the total flow rate of the freeway section (pcu/hr)

3.4. Model Development

The model development in this study, we were applied the simple linear regression and sigmoid function to examine the relationship between independent parameter and shoulder lane utilization as well as to identify the influences parameter contribute to shoulder lane utilization. This study focuses on a random response for variable $Y$ (the shoulder lane utilization) from a set of random variables $X_1, X_2, ..., X_n$ (the related traffic parameter).

In term of linear relationship, the simple linear regression was used as a method to estimate $E(Y/X_1, X_2, ..., X_n)$ through the standard linear regression technique. The equation of simple linear regression was used to estimate the shoulder lane utilization in this study as below Eq. (2):

$$E(Y/X) = \beta_0 + \beta_1 X$$  \hspace{1cm} (2)

where; $\beta_0$ is the constant term usually obtained by least squares; $\beta_1$ is the linear coefficient obtained by least squares;

$X$ is the influences parameter contribute to shoulder lane utilization

The sigmoid function was applied to analyze the nonlinear relationship between independent parameter and shoulder lane utilization as well as to estimate the appropriate coefficient using lease square method. The equation of sigmoid function was used in this study as below Eq. (3):

$$E(Y/X) = \frac{1}{1 + e^{\theta/X}}$$  \hspace{1cm} (3)

where; $\theta$ is the sigmoid function coefficient; $X$ is the parameter affecting shoulder lane utilization;

The modeling functions in the IBM SPSS Statistic are used for statistical analysis. The correlation analysis and backward stepwise technique were adopted to identify the significant parameter and the elimination criteria in this study was considered the Pearson correlation coefficient and statistic p-value of each predictor. In this study the related parameters as used as predictors were shown in Table 1
Table 1
The Predictor Parameters used in this Study

<table>
<thead>
<tr>
<th>Categories</th>
<th>Predictor Parameters</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Stream Parameter</td>
<td>Total Flow Rate</td>
<td>T_{flow}</td>
</tr>
<tr>
<td></td>
<td>Average Speed</td>
<td>T_{speed}</td>
</tr>
<tr>
<td></td>
<td>Total Density</td>
<td>T_{density}</td>
</tr>
<tr>
<td>Relative Parameter from Adjacent Lane</td>
<td>Relative Flow</td>
<td>R_{flow}</td>
</tr>
<tr>
<td></td>
<td>Relative Speed</td>
<td>R_{speed}</td>
</tr>
<tr>
<td></td>
<td>Relative Density</td>
<td>R_{density}</td>
</tr>
<tr>
<td>Driving Environmental</td>
<td>Average Headway</td>
<td>HW_{avg}</td>
</tr>
<tr>
<td></td>
<td>Percentage of Truck or Heavy Vehicle</td>
<td>%Truck</td>
</tr>
<tr>
<td>Benefit from Using of Shoulder Lane</td>
<td>Travel Time saving</td>
<td>TT_{saving}</td>
</tr>
</tbody>
</table>

4. Results and Discussions

4.1. Lane Utilization Characteristic on Expressway Midblock Section

The lane utilization was the result of lane selection behavior which depends on numerous factors (HCM, 2010) and each lane in the same direction regularly had unique characteristics (Lighthill and Whitham, 1955), (Richards, 1956). According to the physical properties of the Kanjanapisek Expressway, we could be classified the midblock section within the study area for 3 categories included; (1) the straight section, (2) the curve section and (3) the grade section. The average value of lane utilization on the Kanjanapisek Expressway revealed that the seven days data collection found the unbalance lane utilization on each section. The highest lane utilization was 43.9% on the median lane (lane 3) followed by the middle lane (lane 2) and the left-most lane (lane 1) respectively. In case of shoulder lane utilization, the results notified that the maximum value of shoulder lane utilization was 7.4% occurred on the Bangkaew-Teparak section; the straight section followed by the PakNam-Bangkru section and the Bangkru-Suksawad which is the grade section respectively. In the case of shoulder lane utilization on the curve section, this study found the use of shoulder lane only 2.0%. The average lane utilization on expressway midblock section were illustrated in Fig. 3

![Average Lane Utilization on Expressway Midblock Section](image_url)

Fig. 3.
Average Lane Utilization on Expressway Midblock Section
4.2. Shoulder Lane Utilization on Expressway Midblock Section

Even though the shoulder lane on the Kanjanapisek Expressway was prohibited but lack of law enforcement and the demand management especially within the rush hour caused the using of shoulder lane remained. In the traffic operator and police officer point of view, during the rush hour both organizations were agreed to occasionally allow drivers using the shoulder lane to provide an additional space for demanded vehicles and reduce travel delay. The average value of shoulder lane utilization on the Kanjanapisek Expressway during the time of day from 6:00AM-6:00PM (12 hours) revealed that the seven days data collection found the fluctuation of shoulder lane utilization during the time of day on each section. The highest shoulder lane utilization was on the 9:00-12:00AM (Off-Peak period) followed by the 3:00-6:00PM (PM Peak period) and the 6:00-9:00AM (AM Peak period) respectively, and the most of shoulder lane utilization was occurred on the Bangkaew-Teparak section followed by the PakNam-Bangkru section and the Bangkru-Sukswad respectively. Average shoulder lane utilization on expressway midblock section during the time of day were illustrated in Fig. 4.

The assumption of this study introduced that the using of shoulder lane will perform once traffic demand exceeded capacity and should be occurred based on mandatory circumstance facilitated by traffic operator. Comparing between the shoulder lane utilization and total flow rate in each expressway section during the time of day, if we classified the flow rate based on total flow level to 3 categories included high-flow level (more than 5,000 pcu/hr), medium-flow level (3,000-5,000 pcu/hr) and low-flow level (lower that 3,000 pcu/hr). The seven days data collection notified that the using of shoulder lane occurred in all flow level and according to the empirical data, most of shoulder lane utilization were appeared in the medium-flow level (3,000-5,000 pcu/hr). Average shoulder lane utilization on expressway midblock section classified by time of day and flow rate were illustrated in Fig. 5.
Fig. 4.
Average Shoulder Lane Utilization on Expressway Midblock Section during the Time of Day

Fig. 5.
Average Shoulder Lane Utilization on Expressway Midblock Section Classified by Time of Day and Flow Rate
4.3. Relationship of Shoulder Lane Utilization and Related Parameters

The lane selection behavior which randomly occurred when motorists were demanding to avoid obstacles or overtaken the lower speed car in the same direction and its involved with numerous factors. In this study, we were focusing on the related parameters contribute to the shoulder lane utilization and in this study the promising parameters were classified to 4 categories as below:

- **Categories 1 : The Traffic Stream Parameters**
  
  In this study, the three major traffic stream parameters were chosen to investigate the relationship among the shoulder lane utilization. The average value of shoulder lane utilization and traffic stream parameter from 5 expressway midblock sections could be summarized that; the total flow rate on expressway midblock section were in ranges 2,000-6,000 pcu/hr and dramatically increased along with the proportion of shoulder lane utilization. The average speed on expressway midblock section were in ranges 60-90 km/hr and slightly reduced once the proportion of shoulder lane utilization increased. The total density on expressway midblock section were in ranges 30-90 pcu/km and it dramatically increased in the same way with the total flow. The relationship between shoulder lane utilization on expressway midblock section and each traffic stream parameters were illustrated in Fig. 6.

![Graphs showing relationships between shoulder lane utilization and traffic stream parameters](image)

(a) Total Flow Rate  
(b) Average Speed  
(c) Total Density

**Fig. 6.**

*Relationship between Shoulder Lane Utilization on Expressway Midblock Section and Traffic Stream Parameter*
Categories 2; Relative Parameters of Adjacent Lane
In this study, the three major relative traffic stream parameters on the adjacent lane of shoulder lane were chosen to investigate the relationship among the shoulder lane utilization. The average value of shoulder lane utilization and relative traffic stream parameter from 5 expressway midblock sections could be summarized that; the proportion of shoulder lane utilization seems to be affected by the relative flow rate on adjacent lane and it increased once the flow rate on lane 1 lower than flow rate on lane 2. In term of relative speed on adjacent lane, the result could be concluded that proportion of shoulder utilization likely increased once the speed on adjacent lane not significantly different on each other and in case of relative density on adjacent lane, it also affected in the same way with the total flow. The relationship between shoulder lane utilization on expressway midblock section and each relative traffic stream parameters were illustrated in Fig. 7.

Categories 3; The Driving Environment
In this study, the driving environment was classified to 2 major parameters including average headway and percentage of truck and heavy vehicle in traffic. The average value of shoulder lane utilization and driving environmental parameter from 5 expressway midblock sections could be summarized that; the proportion of shoulder lane utilization directly affected by the average headway of vehicle on expressway midblock section and it increased once the average headway of vehicle on expressway midblock section was shrinking. In case of the affected by the percentage of truck and heavy vehicle, the relationship notified that the fluctuation of shoulder lane utilization occurred once the percentage of truck and heavy vehicle were lower than 20% and it possibly increased once the percentage of truck and heavy vehicle were in ranges 20%-30%. The relationship between shoulder lane utilization on expressway midblock section and the driving environmental parameters were illustrated in Fig. 8.

Categories 4; The Benefit from Using of Shoulder Lane
In this study, the benefit from using shoulder lane was classified to the average travel time saving which the comparison of travel time from interchange to interchange between using shoulder lane and ordinary lane. The average value of shoulder lane utilization and benefit from using of shoulder lane from 5 expressway midblock sections could be summarized that; the proportion of shoulder lane utilization likely affected by the average travel time saving. The shoulder lane utilization tend to increase once the average travel time saving from using of shoulder lane lower than ordinary lane. Contrastingly, the relationship found that the fluctuation of shoulder lane utilization occurred even though the average travel time saving form using of ordinary lane lower than shoulder lane. The relationship between shoulder lane utilization on expressway midblock section and the benefit from using of shoulder lane was illustrated in Fig. 9.
Fig. 7. 
Relationship between Shoulder Lane Utilization on Expressway Midblock Section and Relative Parameter from Adjacent Lane

(a) Relative Flow Rate

(b) Relative Speed

(c) Relative Density

Fig. 8.
Relationship between Shoulder Lane Utilization on Expressway Midblock Section and Driving Environmental

(a) Average Headway

(b) Percentage of Truck or Heavy Vehicle

Fig. 9.
Relationship between Shoulder Lane Utilization on Expressway Midblock Section and Travel Time Saving
The correlation analysis in this study was used to quantify the relationship between the dependent and independent parameters. Through the correlation analysis using IBM SPSS Statistic software, we estimated the level of correlation between each parameter regarding to the Pearson correlation coefficient which is the most widely used correlation statistic to measure the degree of linear relationship between related parameters. The range of Pearson correlation coefficient was between -1 and +1 to quantifies the direction and strength of the linear relationship between the 2 parameters. The correlation between 2 parameters could be both positive (+) or negative (-) depend on the direction of the relationship and the correlation as close as ±1.00 indicated the strength of relationship between 2 parameters.

In this study, we assumed that the shoulder lane selection behavior in each flow level contain with the different factor thus, based on the empirical data the flow level in this study could be classified as 3 level and beyond that the analysis was also considered the 2-tailed significant value between the dependent and independent parameters in order to organize the appropriate parameter for the multiple regression model. After considering the Pearson correlation coefficient, 2-tailed significant value and relationship direction, the correlation analysis result through the IBM SPSS Statistic software in each flow level was shown in Table 2.

### Table 2

**The Correlation Analysis of Each Predictor Parameters**

<table>
<thead>
<tr>
<th>Predictor Parameters</th>
<th>Analysis</th>
<th>Flow Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low-Flow *</td>
</tr>
<tr>
<td>Total Flow Rate (T_{flow})</td>
<td>Pearson Correlation</td>
<td>0.345</td>
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<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.207</td>
</tr>
<tr>
<td>Average Speed (T_{speed})</td>
<td>Pearson Correlation</td>
<td>-0.093</td>
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<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.743</td>
</tr>
<tr>
<td>Total Density (T_{density})</td>
<td>Pearson Correlation</td>
<td>0.361</td>
</tr>
<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.187</td>
</tr>
<tr>
<td>Relative Flow (R_{flow})</td>
<td>Pearson Correlation</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.851</td>
</tr>
<tr>
<td>Relative Speed (R_{speed})</td>
<td>Pearson Correlation</td>
<td>0.198</td>
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<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.478</td>
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<tr>
<td>Relative Density (R_{density})</td>
<td>Pearson Correlation</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.899</td>
</tr>
<tr>
<td>Average Headway (HW_{avg})</td>
<td>Pearson Correlation</td>
<td>-0.122</td>
</tr>
<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.664</td>
</tr>
<tr>
<td>Percentage of Truck or Heavy Vehicle (%Truck)</td>
<td>Pearson Correlation</td>
<td>-0.116</td>
</tr>
<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.681</td>
</tr>
<tr>
<td>Travel Time saving (TT_{saving})</td>
<td>Pearson Correlation</td>
<td>0.304</td>
</tr>
<tr>
<td></td>
<td>Two-Tailed Significant</td>
<td>0.270</td>
</tr>
</tbody>
</table>

Note: * 15 samples, ** 839 samples and *** 504 samples
The correlation of each predictor on different flow level could be discussed as below:

- **Low Flow Level; flow rate lower than 3,000 pcu/hr**
  The analysis of Pearson correlation coefficient and 2-tailed significant in the low flow level circumstance, the result indicated that within 5 expressway sections and 12 hours of data collection (between 06.00AM-06.00PM), this study captured only 15 samples and there was no significant parameter correlated to the shoulder lane utilization.

- **Medium Flow Level; flow rate between 3,000-5,000 pcu/hr**
  The analysis of Pearson correlation coefficient and 2-tailed significant in the medium flow level circumstance, the result indicated that within 5 expressway sections and 12 hours of data collection (between 06.00AM-06.00PM), this study captured 839 samples and the parameter correlated to the shoulder lane utilization in positive direction included the total density, relative speed and travel time saving. On the other hand, the average speed, average headway and percentage of truck and heavy vehicle were correlated to the shoulder lane utilization in negative direction.

- **High Flow Level; flow rate higher than 5,000 pcu/hr**
  The analysis of Pearson correlation coefficient and 2-tailed significant in the high flow level circumstance, the result indicated that within 5 expressway sections and 12 hours of data collection (between 06.00AM-06.00PM), this study captured 504 samples and the parameter correlated to the shoulder lane utilization in positive direction included the total flow rate, total density and relative flow. Otherwise, the average headway, average speed and percentage of truck and heavy vehicle were correlated to the shoulder lane utilization in negative direction.

The result could be concluded that each flow rate condition of traffic stream affects to the shoulder lane utilization and each flow level has unique characteristic. Considering the correlated direction, the parameter that correlated in positive direction which mean that those of the parameter are directly related to the shoulder utilization, the higher of the parameter, the greater of the shoulder utilization. Alternatively, the parameter that correlated in negative direction which mean the those of the parameter are inversely related to the shoulder lane utilization.

### 4.4. Model Development for Shoulder Lane Utilization

In order to identify the influenced factor that contribute to shoulder lane utilization on expressway midblock section as well as develop the regression model to estimate the shoulder lane utilization. This study proposed the simple linear regression models to perform the linear relationship and the sigmoid function to perform the nonlinear relationship in order to estimate the shoulder lane utilization on Kanjanapisek Expressway. Based on the stepwise analysis in the IBM SPSS statistic software, the result indicated that the most influencing factor contribute to the shoulder lane utilization was the total density and the appropriate coefficient for simple linear regression model could be described in Table 3.
### Table 3
The Statistic Value for Simple Linear Regression Model

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjust R Square</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Linear Regression</td>
<td>0.519</td>
<td>0.269</td>
<td>0.268</td>
<td>0.039</td>
</tr>
<tr>
<td><strong>Coefficients</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-0.037</td>
<td>0.004</td>
<td>-8.903</td>
<td>0.000</td>
</tr>
<tr>
<td>Total Density</td>
<td>0.001</td>
<td>0.000</td>
<td>22.169</td>
<td>0.000</td>
</tr>
</tbody>
</table>

*Source: Result of IBM SPSS Statistic software with stepwise analysis*

As for sigmoid function modelling, the regression curve estimation and nonlinear function in the IBM SPSS statistic software was used to estimate the appropriate coefficient through the least square method. The modelling result for sigmoid function could be shown in Table 4.

### Table 4
The Statistic Value for Sigmoid Function Model

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjust R Square</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-Curve Estimation</td>
<td>0.561</td>
<td>0.315</td>
<td>0.315</td>
<td>0.079</td>
</tr>
<tr>
<td><strong>Nonlinear Coefficients</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sigmoid Coefficients (θ)</td>
<td>210.064</td>
<td>2.209</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: Result of IBM SPSS Statistic software with curve estimation analysis*

![Graph showing model fitting of simple linear regression and sigmoid function](image)

**Fig. 10.**
Model Fitting of Simple Linear Regression and Sigmoid Function

### 4.5. Comparison of Shoulder Lane Utilization Model

In order to validate the performance of developed model, a new set of data collection were used. In this study, we evaluated the performance of developed model in term of residuals error of the shoulder lane utilization estimation based on the different flow level and geometry of expressway. The
overview of model performance could be concluded that the sigmoid function likely to provide a better fit in term of shoulder lane utilization estimation. Based on the different flow level, the results show that the average residuals error of the estimation from sigmoid function in each flow level lower than the simple linear regression especially in medium flow and high flow level. In case of the different geometry of expressway, the result show that the average residuals error of the estimation from sigmoid function also lower than the simple linear regression and both of developed model has highly fluctuated in straight section.

However, if we consider in the performance of both models, it proves that both of the proposed model performed reasonably and fitted with low residual errors and could be applied to estimate the shoulder lane utilization in the midblock section of expressways. The residuals error of shoulder lane utilization estimation based on different flow level and geometry of expressway could be described in Fig. 11.

Fig. 11. The Residuals Error of Shoulder Lane Utilization Estimation Based on Different Flow Level and Geometry on Expressway
5. Conclusion

This study investigated the characteristic of shoulder lane utilization behavior, identified significant parameters effecting shoulder lane utilization behavior and compared the empirical data with linear regression model and sigmoid function. In summary, the shoulder lane utilization behavior under different flow condition has unique characteristic. The most influenced factors that contributes to shoulder lane utilization was the total density which consistent with previous studies (Knoop et al., 2010), (Samoilli et al., 2013).

The relationship between the influenced factor and the shoulder lane utilization was found to be nonlinear. By applying the developed models to several locations on expressway, it has been proved that the sigmoid function provides a better performance than the simple linear regression. Even though the comparison revealed that the performance of simple linear regression was worse than the sigmoid function, it provided acceptable result in terms of shoulder lane utilization estimation on the Kanjanapisek Expressway.

The expectation of this study was to understand the driving behavior and gain the knowledge from empirical data which will help the traffic operator come up with appropriate traffic management scheme. It should be noted that this study has focused on the macroscopic scale of discretionary lane change to shoulder lane on expressway midblock section which currently violated to the local law regulation. Development of the proposed model was performed by using empirical data covering only cases where shoulder lane utilization is under 30%. Further research is needed to develop model for higher shoulder lane utilization.

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