COMPARISON OF ACCEPTED GAPS FOR DIFFERENT ON-STREET PARKING DESIGNS

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Abstract
Potential problems could arise when drivers leave their parking stalls and merge into the main traffic stream. These problems could partly be attributed to finding acceptable gaps to merge into with safety and without causing undue difficulties to following vehicles. Observations from a variety of sites show different distributions of gap acceptance depending mainly upon the design and layout of parking stalls. Three chosen sites, including parallel parking and angle parking (both at 45 and 90 degrees) have been selected for this study. The surveys have been conducted using videoing techniques. The results show that the mean accepted gaps for angle parking are higher than that for parallel parking. The statistical tests indicate that there is no significant difference between the two types of angle parking. However, significant differences exist between them and those for parallel parking. This could be attributed to the type of manoeuvres associated with merging operations which are likely to involve backing-out (reversing) from the stalls in the case of angle parking. Some drivers experience difficulties with such manoeuvres which could lead into forced merging situations. This behaviour requires further investigation.

Key words: *on-street parking, stall design, gap acceptance and merging behaviour*

1. Merging at On-street Parking

The consequences of merging operations at on-street parking are sometimes overlooked in the process of parking design and provision of alternative traffic management schemes. Previous studies have shown that there are potential traffic interruptions and temporary congestion in the main traffic lanes near on-street parking areas. These are caused by merging manoeuvres from parking stalls 'leaving' which could require relatively longer durations especially when angle parking are in operation[1]. Further work by Purnawan and Yousif[2] showed that 'entering' manoeuvres into parking stalls could also create disruption to the traffic stream.

In the process of merging, drivers select an acceptable gap to join the main traffic stream. This is similar to merging at uncontrolled junctions where the operation is governed by the availability of sufficient gaps in the main traffic stream[3]. Because of the relatively longer duration for backing-out manoeuvres for on-street parking, drivers require relatively longer accepted gaps to complete the manoeuvre in a safe manner[4]. However, when the level of traffic volumes are high, the headways between successive vehicles are relatively small. Therefore, there is a potential of forced merging occurring alongside on-street parking areas. These may influence the following traffic causing temporary delays and queues. The problem becomes even worse, where angle parking areas are situated on busy roads with two-way traffic[1].

Therefore, better understanding of on-street parking operations is necessary, hence this work describes observations of gap acceptance from a variety of parking layouts and their possible effects on operation.

2. Observations of Gap Acceptance

The accepted gaps and lags are measured when a vehicle starts to move in order to merge into the main traffic stream. The reference point of measurement is determined at the conflict point of the merging locations. These conflict points are dynamic and their position changes alongside the parking stalls. The term, gap is defined as the time between successive vehicles in the main traffic stream. When a vehicle merges from a parking stall, an accepted gap is selected which usually consists of two elements (i.e. lead and lag) as shown in Figure 1. The lag in this discussion is defined as the time between the merging vehicle and the arrival of a vehicle from the main traffic stream at a reference point where the merge occurs. The lead is the time between the passing vehicle from the main stream and the merging vehicle at the reference point (i.e. the remaining time of the gap after subtracting the lag component).

Yousif and Purnawan[1] reported that there were different patterns of merging manoeuvres. However, observations have shown that most drivers follow the merging patterns shown in Figure 1 for both parallel and angle parking when leaving the parking stalls. Therefore, any accepted gaps in the case of angle parking which involves direct leaving manoeuvres (i.e. without reversing) are ignored. This is because of the very small sample size related to such manoeuvres. In this study, the maximum value of accepted gap is considered to be in the region of 30 seconds. This value is based on observations which suggest that the majority of drivers are able to complete their leaving manoeuvres within that period of time.

For data collection, a portable video camera (with a character generator giving the time to the nearest 1/100 seconds) was used to capture the detailed merging behaviour of parked vehicles. Each site was filmed for more than 6 hours (sometimes visited twice). A total of 30 hours of data captured on videos was available for analysis. The video tapes were then played back to extract the necessary data. The data were analysed using statistical and spread sheet software.

Three sites with on-street parking have been selected to compare the effect of different designs of stalls on the accepted gaps when leaving a parking stall. Those sites include parallel parking, angle parking at 45 degrees and angle parking at 90 degrees. All sites are within the Greater Manchester Area in the United Kingdom. The size of parking stalls are 2.1m x 6.1m, 2.1m x 4.3m and (2 x 2.7)m x 4.1m for parallel parking, angle parking at 45 degrees and angle parking at 90 degrees, respectively. Based on the Traffic Signs Regulations and General Directions (TSRGD) United Kingdom 1994[5], those sizes of parking stalls are considered to be acceptable.

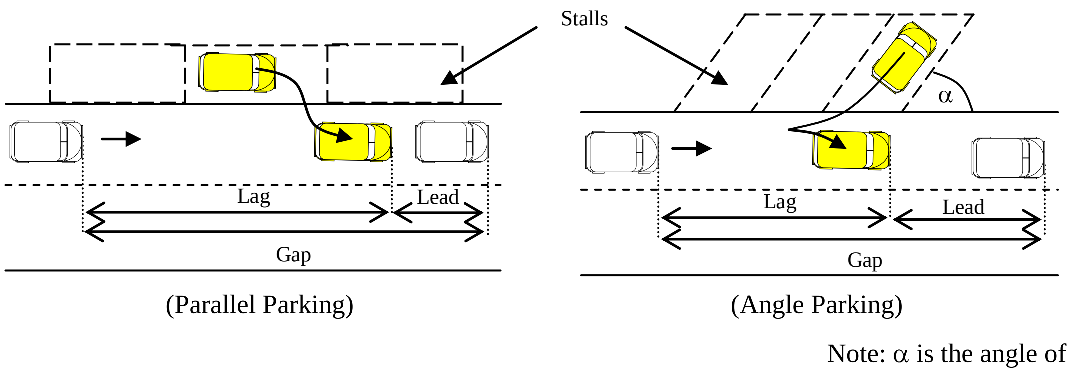

Figure 1: Merging at on-street parking

3. Results and Analysis of Data

a. Differences between mean accepted gaps, lags and leads - The mean and standard deviation of accepted gaps, lags and leads for the selected parking types are shown in Table 1. The values of the mean accepted gap and lag at parallel parking are the lowest. These could be attributed to the fact that leaving manoeuvres at parallel parking do not involve reversing and hence require relatively shorter accepted gaps and lags. Whereas in the case of angle parking (both 45 and 90 degrees) the manoeuvres are likely to involve reversing. The Table also shows the combined mean and standard deviation for the total sample size of both angle parkings (i.e. 45 and 90 degrees) in order to allow comparison with those of parallel parking.

Table 1: Gaps, lags and leads at on-street parking

Parking type	Gap			Lag			Lead		
	$\bar{x}$ (sec)	σ (sec)	n	$\bar{x}$ (sec)	σ (sec)	n	$\bar{x}$ (sec)	σ (sec)	N
Parallel	12.8	5.1	34	8.3	4.2	34	4.5	4.1	34
Angle 45°	15.6	6.1	93	13.2	5.0	93	2.4	2.9	93
Angle 90°	16.2	5.3	72	12.3	5.3	72	3.8	3.9	72
Angle 45° + 90°	15.8	5.7	165	12.8	5.2	165	3.0	3.4	165

Statistical analysis for the different mean accepted gaps, lags, and leads has been conducted. The results of this analysis are as shown in Table 2. The difference of mean accepted gaps and lags between parallel parking and those for angle parkings are significantly different at the 5% level of significance. However, the comparison between the two types of angle parking (i.e. 45 and 90 degrees) reveals that the mean accepted gaps and lags are not significantly different at the 5% level of significance.

Table 2: Difference in the means of gaps, lags and leads between the different types of layouts

Mean difference	Gap			Lag			Lead		
	$Z_{0.025}$	Z_{cr}	$\mu_i = \mu_j$	$Z_{0.025}$	Z_{cr}	$\mu_i = \mu_j$	$Z_{0.025}$	Z_{cr}	$\mu_i = \mu_j$
Parallel – Angle 45°	2.60	1.96	SD	5.89	1.96	SD	2.82	1.96	SD
Parallel – Angle 90°	3.18	1.96	SD	4.24	1.96	SD	0.77	1.96	NSD
Parallel – Angle 45° + 90°	3.13	1.96	SD	5.50	1.96	SD	1.95	1.96	NSD
Angle 45° - Angle 90°	0.69	1.96	NSD	1.03	1.96	NSD	2.66	1.96	SD

Note: - $Z_{0.025} = |\bar{X}_i - \bar{X}_j| / [(\sigma_i^2/n_i) + (\sigma_j^2/n_j)]^{1/2}$

- SD: significant difference
- NSD: not significantly different

The mean lead values for parallel parking compared with the combined sample of angle parking are 4.5 and 3.0 seconds, respectively as shown in Table 1. The statistical test indicates that there is no significant difference between these two means at the 5% level of significance. Because of this similarity in lead values between parallel and angle parking, it is decided not to further the discussion on the time lead. Therefore, the following discussion will only be focused on the lag values and their distribution for the different types of parking layouts.

b. Distribution of accepted lags – The previous section shows that there are differences in the lag component of the gap for the different types of parking layouts. The distributions of these lags are as shown in Figure 2. The statistical analysis on the Goodness of fit test, as shown in Table 3, indicates that those accepted lag distributions at parallel parking and parking at 45 degrees can be represented by the normal distribution at the 5% level of significance.

Table 3: Goodness of fit test (Normality) for accepted lags using Chi-square method

Parking type	$\bar{x}$ (sec)	σ (sec)	Min (sec)	Max (sec)	n	DF	χ^2 Calculated	$\chi^2_{0.05}$ Critical	Note
Parallel	8.3	4.2	2.0	17.6	34	3	4.60	7.82	Normal
Angle 45°	13.2	5.0	4.7	27.4	93	5	3.00	11.07	Normal
Angle 90°	12.3	5.3	1.5	25.3	72	4	14.12	9.49	Not Normal

The distributions show that the accepted lag for parallel parking is shifted to the left compared with the other distributions for angle parking. At parallel parking, drivers require relatively shorter maximum accepted lags than at angle parking. Minimum accepted lags are associated with ‘forced merging’ behaviour. Drivers leaving their parking stalls greatly influence those on the main traffic stream either by forcing them to reduce their speeds (and sometimes stop) or by blocking the lane in front of them causing them to swerve or change lanes. More detailed analysis is required on 'forced merging' behaviours. Therefore, it is necessary to provide appropriate designs for on-street parking stalls to reduce the frequency of such behaviours and to improve safety.

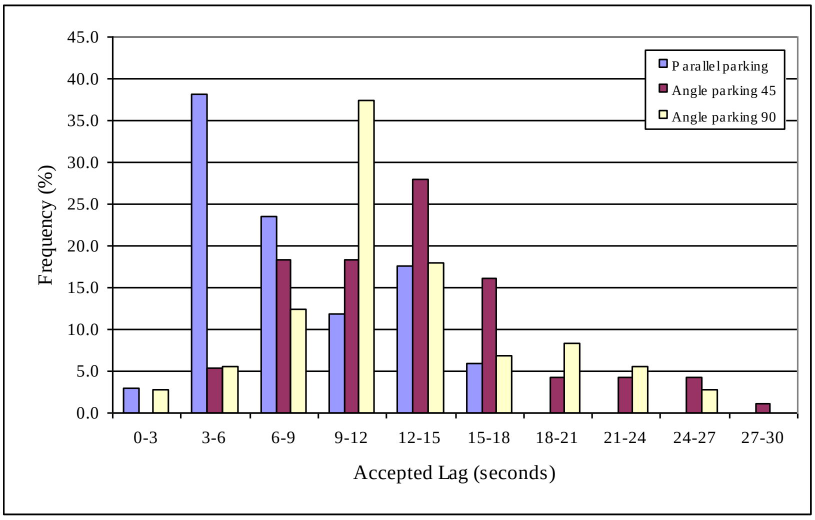

Figure 2: Distributions of accepted lag

4. Conclusions

- Results from the statistical analysis of the mean accepted gaps, lags, and leads for the different on-street parking layouts suggest that there are significant differences in the mean accepted gaps and lags between parallel parking and angle parking at the 5% level of significance.

- For angle parking, the mean accepted gaps and lags are higher than those at parallel parking. This could be attributed to the backing-out manoeuvres associated with angle parking.

- Comparisons between the distributions of accepted lags for the different on-street parking layouts reveal that at parallel parking, drivers tend to accept shorter lags compared with those at angle parking.

- Safety issues and other problems will be raised in association with those minimum accepted lags leading to 'forced merging' behaviours. Therefore, it is necessary to explore the consequences of those behaviours alongside on-street parking areas in more details.

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