# A METHODOLOGY FOR DEPICTING DRIVERS' TIME HEADWAY PREFERENCES THROUGH ANPR TECHNOLOGY

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## ABSTRACT

Car following behaviour has road safety implications. The idea of identifying those vehicles that were captured being in a close-following instance through Automatic Number Plate Recognition (ANPR) technology was the motive of the research. The present paper attempts to investigate whether meaningful interpretation of time headways is possible when vehicle identities are taken into account. Using a set of ANPR data collected in Thurles, Republic of Ireland, a number of empirical observations, which deserve further attention, were made. It was found that the distribution of headways with respect to time was more skewed towards the left compared with the overall distribution of all data which had no particular reference to the vehicle identities. It was also interesting to show preliminarily that the standard deviation of the time headways (with vehicle identities taken into consideration) was smaller than the spread of the randomly picked headways from the overall population. As a result, we highlight the need for further research to explore the issue more from both academic studies' and enforcement bodies' points of view.

*Keywords: number plate recognition, safety, close following*

## INTRODUCTION

In traffic engineering, vehicular headway studies are carried out by measuring the gap between successive vehicles. There are two types of headways: time headways and distance headways (also called spacing). A time headway is defined as the time interval between successive vehicles (from a reference point of the first vehicle to the same reference point of the second vehicle) as they pass a point along the lane (Roess et al., 2004). In headway-related studies, the collected data give an idea about headways without making any particular reference to the identities of individual vehicles. In other words, the time gaps are recorded between the vehicles in the order of their arrivals at a specific point on the road. The (random) vehicle pairs are, therefore, formed naturally. Hence, all analyses, such as mean headways, standard deviations, and statistical headway distributions, are based on the overall sample population. Whereas those conventional headway studies, in a sense, look at a snapshot of the headway data, the present paper attempts to follow the time headway preferences of individual vehicles over some period of time along the road network by means of Automatic Number Plate Recognition (ANPR) technology. If these meaningful relationships do, in fact, exist, then a number of useful practical implications can be considered. For example, if we can identify those vehicles that have a tendency to keep dangerously short headways in most of the captures, then the drivers of these vehicles can be contacted and warned by the authorities for safer roads.

The behaviour of following the vehicle in front with headways shorter than the recommended safe thresholds (usually 2.0 seconds) is commonly referred to as close-following or tailgating. This behaviour is considered to be risky as far as road safety is concerned and some countries even have penalties for drivers who close-follow (e.g. Schweitzer et al., 1995). Various studies have been conducted to investigate the relationship between close-following and safety (rear-end collisions in particular), although Brackstone and McDonald (2007) have reservations about the statements such as 'drivers drive too closely' and 'constant time headways', arguing that these rules are based largely on little quantitative substantiation. Evans and Wasielewski (1982) showed that, in a particular study sample, nearly half of those who drove with a time headway of less than 1 second had been involved in an accident some time in the past and almost two-thirds had at least one offence on their record, whereas the corresponding figures for those with a time gap of 1 second or more were considerably smaller. Michael et al. (2000) reported that 27.2% of all crashes happened in Tennessee in one year were rear-end collisions and following too closely was the contributing factor in nearly a third of these cases. Summala (1980) found that overtaking bans on two-lane rural highways reduce the frequency of short headways, while Rajalin et al. (1997) stated that close-following leads to high accident rates, and based on the interviews with drivers, they discovered that close-following becomes a 'habit'.

Researchers used various empirical methods in headway-related studies. In addition to the video recording and analysis of real-world traffic flow (e.g. Gunay, 2007-a), driving simulators were used to investigate driving behaviour and reaction times (e.g. Hoffmann and Mortimer, 1994; Van Winsum and Brouwer, 1997). Smart car technology and instrumented or probe vehicles enabled researchers to study car-following behaviour (e.g. McDonald, et al., 1997; Summala et al., 1998; Boyce, 1999; Brackstone, 2001; Neale et al 2005; Brackstone, 2007). Similarly, global positioning systems were facilitated in car-following studies to analyse headways, speed, acceleration and deceleration characteristics of vehicles (e.g. Wolshon, 2000), but these applications were limited by the small number of vehicles fitted with these in-vehicle units compared with the total number of vehicles in the whole traffic population in a study area. The most common use of Automatic Vehicle Identification (AVI) systems is travel time, speed information (Dixon and Rilett, 2005) and OD estimation (Chang, 1995; Dixon and Rilett, 2002). Gunay (2007-b) theoretically investigated the stochastic nature of two vehicles being in a macroscopic car-following state based on a possible ANPR data application. The present paper will demonstrate a new use of ANPR technology in order to understand vehicle headways, particularly in terms of the analysis of individual drivers' headway preferences and the scrutiny of close-following tendencies, better.

# THE DATA

In order to discuss our argument, we used a set of data, collected in Thurles, County Tipperary, Republic of Ireland on 7th September 2006. Video-recording systems were installed at each location to capture the registration plates of vehicles by means of ANPR technology. The survey was conducted at 20 sites, (Table 1 and Figure 1), by a consultancy firm. The survey period was from 07:00 to 19:00 hours. A four-fold classification was used and comprised: cars, light goods vehicles, buses and coaches, and heavy goods vehicles. The traffic composition of the whole population was 80% cars, 13% light goods vehicles, 1% busses, and 6% Heavy Goods Vehicles (HGVs). The present paper did not, however, separate the analyses for these different vehicle classes, since the majority (93%) were cars and vans. Consideration of slow-moving vehicles in other studies may become important if the proportion of heavy vehicles is large.

Table 1: Data collection site characteristics

| Site No | Direction | Location description |
|---|---|---|
| 1 | East Bound | R498 Grange Road, adjacent to the racecourse |
| 2 | West Bound | |
| 3 | North Bound | Local road to Liscahill, the north of the hospital |
| 4 | South Bound | |
| 5 | NW Bound | N52, the north of Thurles at Grange |
| 6 | SE Bound | |
| 7 | NE Bound | Local road to Farranreigh, at Bohernamona |
| 8 | SW Bound | |
| 9 | East Bound | Local road to Loughlahan, at Lognafulla |
| 10 | West Bound | |
| 11 | East Bound | N75 Dublin Road, at Wrensborough |
| 12 | West Bound | |
| 13 | North Bound | Local road to Archerstown Bridge the north of Mullauns |
| 14 | South Bound | |
| 15 | NW Bound | N62, the south of Thurles at Turtulla Bridge |
| 16 | SE Bound | |
| 17 | NE Bound | R659 Cabra Road, the north of Cabragh Bridge |
| 18 | SW Bound | |
| 19 | East Bound | R660 Abbey Road, at Garryvicleheen |
| 20 | West Bound | |

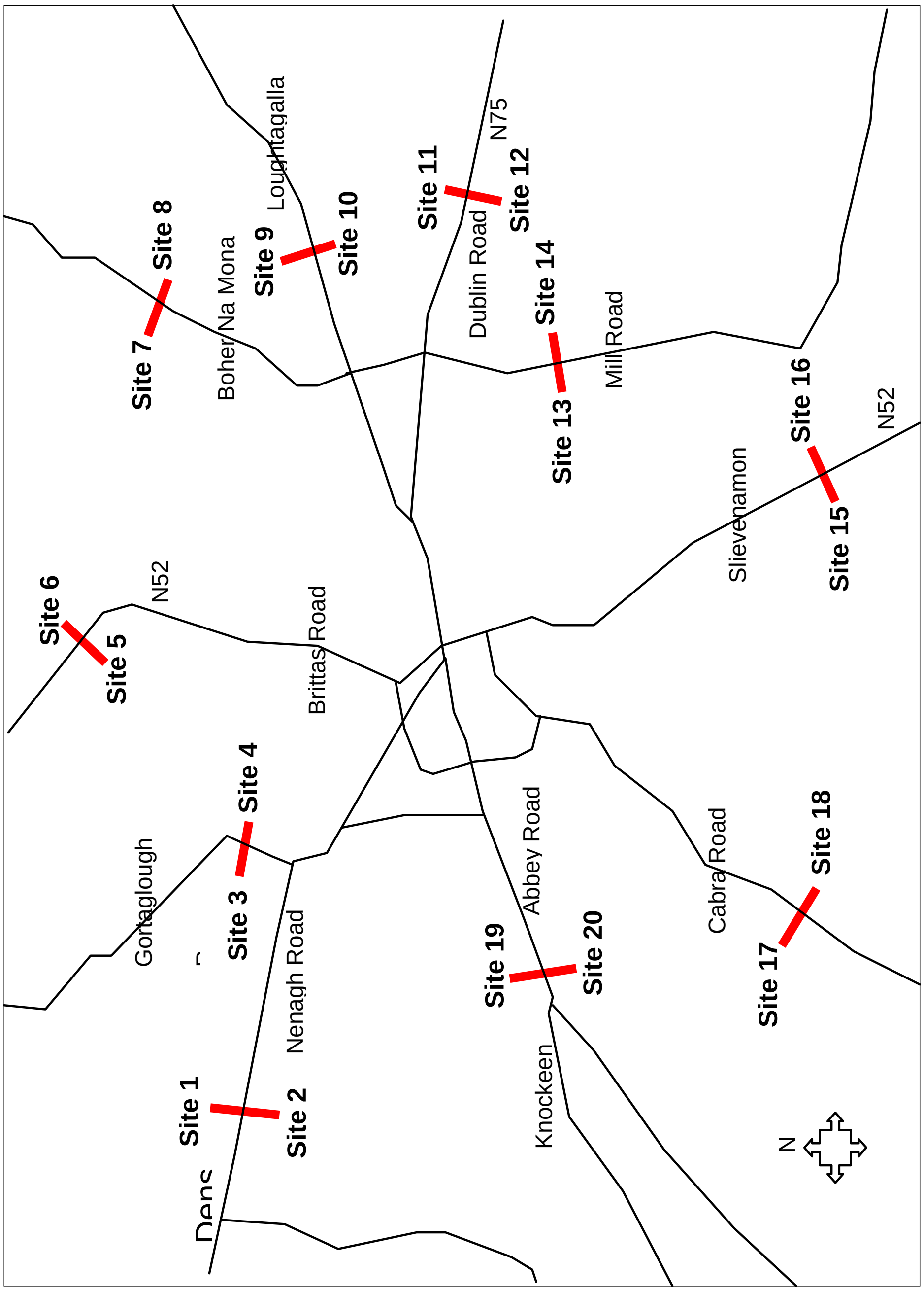


Figure 1: A map of the data collection sites, Thurles, Ireland, not to scale.

The road and traffic characteristics of all sites were similar so that the vehicles studied in the data were spotted in more or less the same conditions over the network. In total, 34,332 number plates were recorded at all 20 sites. These vehicles are not necessarily all unique vehicles, since some were spotted more than once during the survey period, as will be examined later. These 34,332 vehicles resulted in 34,312 headways (i.e. 34,332 – 20). The study period was in a single day, rather than over many days, as we wanted to increase the chance of the same vehicle being driven by the same person during the observation period. It was reported that, during the data collection period, the weather was mostly cloudy with some sunny spells throughout the day. No accidents happened during the survey.

The ANPR data were obtained in MS Excel spreadsheets, which contained the registration plate reading of each vehicle, the site number, the time of ANPR capture for each vehicle (i.e. arrival times), and the vehicle types. The expressions 'number plate' and 'registration plate' are used interchangeably in the paper. Due to privacy concerns, the plate readings were encrypted immediately for the rest of the analyses. To do this, a small algorithm was used, as shown in Figure 2. Similar techniques have been proposed by others (e.g. Dalgleish and Hoose, 2008; Howe, 2009).

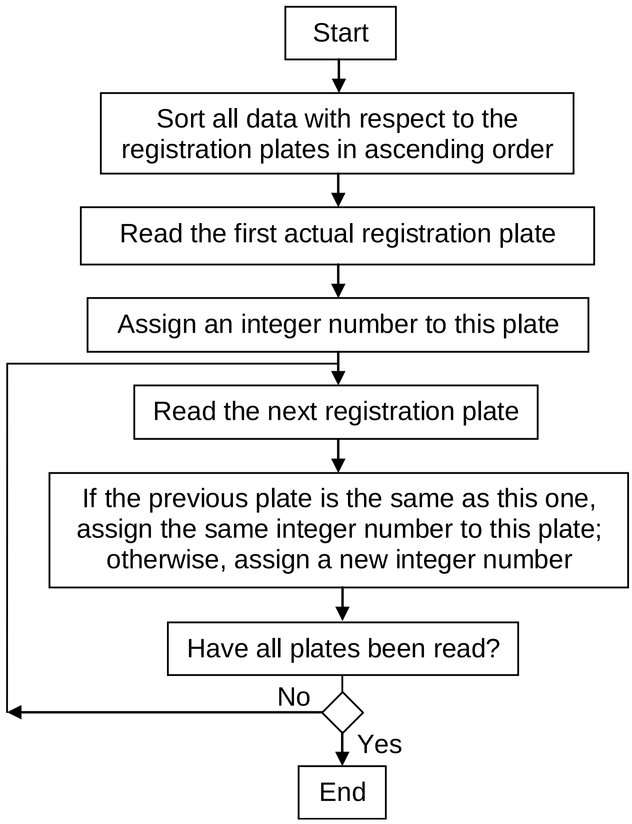


Figure 2: An algorithm showing the encryption of the actual number plates.

As a result, each unique plate became a unique number between 1 and 10,024. This means that, out of 34,332 number plate recordings, 10,024 unique vehicles were identified, and the rest were the repeat appearances of these vehicles captured more than once. A computer program, which was able to read from spreadsheet files, was written in Borland C++ language to analyse the appearances of these vehicles and the associated time headways throughout the survey period. A part of the outcome of this analysis is shown in Table 2.

Some of the vehicles were spotted more than once at quite regular intervals, probably suggesting a number of scheduled public transport vehicles. Note that, if the data collection period had started earlier (or ended later), it would have been quite possible for, say, the 'captured twice' vehicles to be a part of the 'captured more than twice' group. No further importance should, therefore, be attached to the distribution of the figures over the numbers of captures in Table 2.

Table 2: Frequencies of registration plate captures

| The number of times the same registration plate is captured | The number of unique vehicles |
|---|---|
| **2** | 5900 |
| **3** | 786 |
| **4** | 1938 |
| **5** | 305 |
| **6** | 517 |
| **7** | 129 |
| **8** | 210 |
| **9** | 59 |
| **10** | 75 |
| **11** | 15 |
| **12** | 35 |
| **13** | 13 |
| **14** | 16 |
| **15** | 9 |
| **16** | 5 |
| **17** | 3 |
| **> 18** | 9 |
| **Total** | **10,024** |

## HEADWAY DISTRIBUTIONS WITH AND WITHOUT VEHICLE IDS

We first studied the time headways between all vehicles without taking the vehicles' registration plates into account. This was simply the time difference between the arrivals of the subject vehicle and the previous vehicle (which passed the camera before the subject vehicle). Figure 3 summarises the distribution of these time headways, which will be discussed later in the paper.

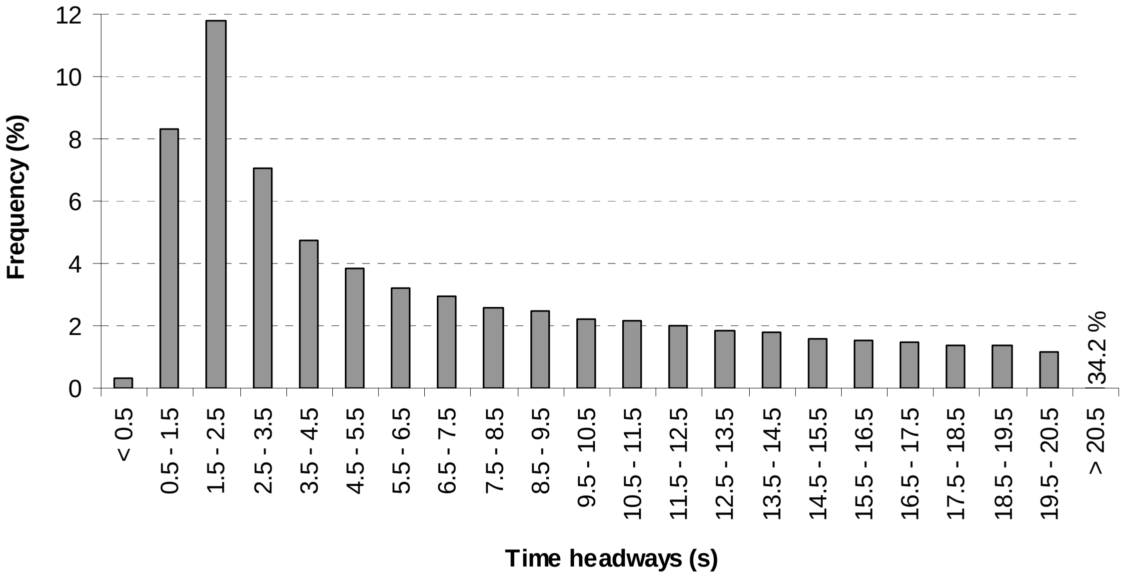


Figure 3: Time headway distribution of all captured vehicles (34,312 headways).

The next step was to identify and group the time headways for the same subject vehicles that were spotted more than once during the survey period. For example, Figure 4 shows a case where the subject vehicle was captured three times at Sites 1, 11, and 15. In each capture, the subject vehicle happened to follow a different vehicle (*X*, *Y*, and *Z*). The computer program developed was able to identify, from the spreadsheets, the number plates of these vehicles (including the subject vehicle) and their arrival times at these sites.

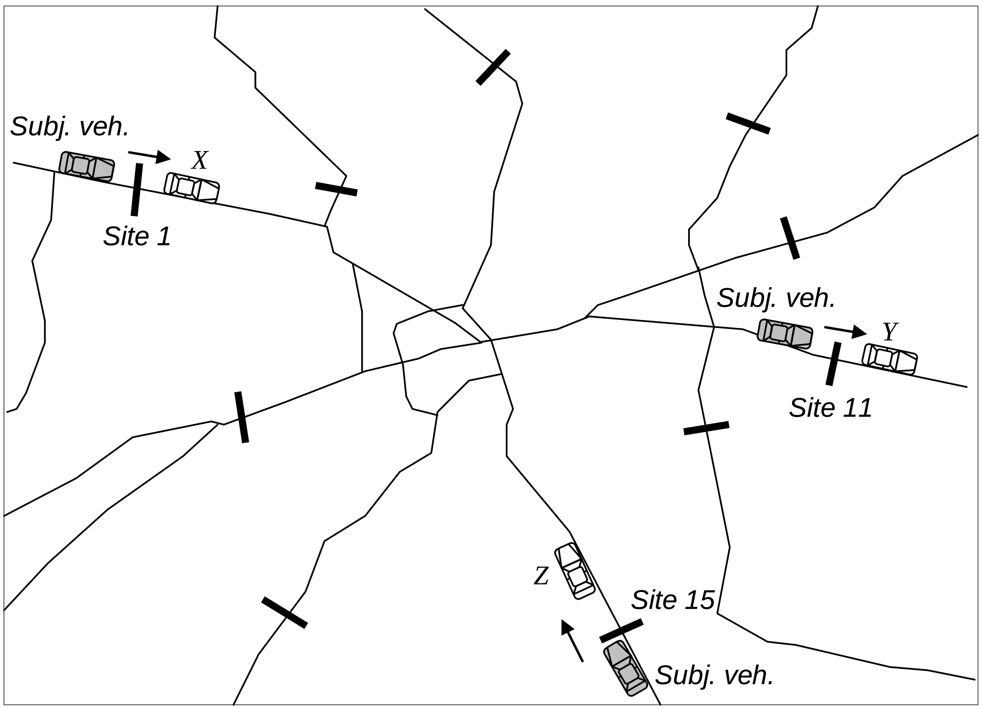


Figure 4: Demonstration of a "captured three times" case as an example, not to scale.

This enabled us to see the magnitudes of the time headways for every subject vehicle (spotted more than once) throughout the study period. Table 3 shows part of the results, where, for example, a subject vehicle with the (encrypted) number plate of 7631 was captured five times during the study period. The time headways between this (subject) vehicle and the vehicle in front (not necessarily the same leading vehicle in each capture) are 3, 1, 2, 41, and 1 seconds respectively. Also note that each capture does not have to take place at a different site, as the subject vehicle can well be spotted at the same site more than once at different times (though this was not very common in our study).

Table 3: A part of the occurrence file with time headways for illustration purposes

| **Reg. Plate** | **Number of occurrences** | **Time headways (s)** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1st capture** | **2nd capture** | **3rd capture** | **4th capture** | **5th capture** | **…** |
| **1** | **7** | 3 | 2 | 4 | 9 | 3 | … |
| **…** | **…** | **…** | **…** | **…** | **…** | **…** | **…** |
| **7630** | **3** | 2 | 1 | 4 | | | |
| **7631** | **5** | 3 | 1 | 2 | 41 | 1 | |
| **7632** | **2** | 8 | 3 | | | | |
| **…** | **…** | **…** | **…** | **…** | **…** | **…** | **…** |
| **10,024** | **16** | 5 | 2 | 6 | 19 | 17 | … |

A further analysis of the data revealed interesting findings when we paired the time headways of those vehicles captured twice or more and compared the first and the second captures of each pair of the 'same' vehicle. For example, each bar in Figure 5 with a different shading pattern represents the time headways of those 10,024 vehicles in their initial capture (see the legend of the diagram). The *x* axis of the diagram shows the time headways of the 'same' vehicles in their next capture. While the first captures are odd number ($1^{st}$, $3^{rd}$, $5^{th}$ , etc.) captures, the next captures became even number ($2^{nd}$, $4^{th}$, $6^{th}$, etc.) captures. Namely, the bars in Figure 5 contain all the headways in the:

$1^{st}$ and $2^{nd}$ captures of 10,024 vehicles (that are captured twice or more),
$3^{rd}$ and $4^{th}$ captures of 3,338 vehicles (that are captured four times or more),
$5^{th}$ and $6^{th}$ captures of 1,095 vehicles (that are captured six times or more),
$7^{th}$ and $8^{th}$ captures of 449 vehicles (that are captured eight times or more),
$9^{th}$ and $10^{th}$ captures of 180 vehicles (that are captured ten times or more), and so on.

See Appendix A for the calculation of the above numbers of vehicles. Note that, by the term 'headway', we mean the time gap between the subject vehicle in question and the vehicle in front. To aid clarity, only the first five intervals are shown in the legend of the figure.

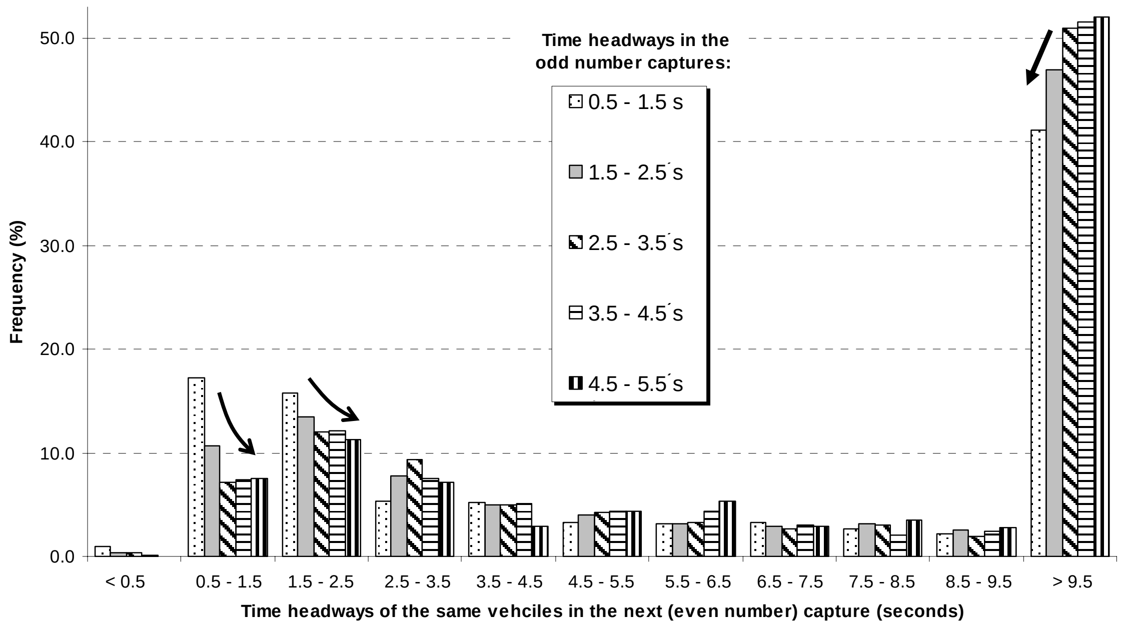


Figure 5: Frequency diagram of time headways for vehicles captured twice or more.

The bar that is furthest to the left (with a dotted pattern) in each category, for example, shows the frequency distribution (in the next capture) of those vehicles that had 0.5-1.5 seconds' headway in their previous capture. That is to say, as Table 4 summarises, 17.2% of the vehicles in the first group, in the next capture kept the same headway of 0.5-1.5 seconds as in the previous capture. A total of 15.7% of the vehicles in the second group kept a higher gap of 1.5-2.5 seconds in the next capture, and so on. Another interesting feature of Figure 5 is the decreasing frequencies at small headway values. This shows that a higher rate of those drivers (who kept a short headway in the first spot) tends to keep, again, short headways in the next spot.

Table 4: The percent frequency matrix between the two consecutive captures of the same vehicle

| Headways (of the same vehicles) in their next capture (seconds) | Headways in the previous capture (seconds) | | | | |
|---|---|---|---|---|---|
| | **0.5 - 1.5** | **1.5 - 2.5** | **2.5 - 3.5** | **3.5 - 4.5** | **4.5 - 5.5** |
| **<0.5** | 1.0% | 0.3% | 0.4% | 0.2% | 0.0 |
| **0.5 - 1.5** | 17.2% | 10.7% | 7.1% | 7.3% | 7.5% |
| **1.5 - 2.5** | 15.7% | 13.4% | 12.0% | 12.1% | 11.3% |
| **2.5 - 3.5** | 5.3% | 7.8% | 9.3% | 7.5% | 7.1% |
| **3.5 - 4.5** | 5.2% | 5.0% | 5.0% | 5.1% | 3.0% |
| **4.5 - 5.5** | 3.3% | 4.0% | 4.3% | 4.3% | 4.4% |
| **5.5 - 6.5** | 3.2% | 3.2% | 3.3% | 4.3% | 5.3% |
| **6.5 - 7.5** | 3.3% | 2.9% | 2.7% | 3.0% | 3.0% |
| **7.5 - 8.5** | 2.6% | 3.1% | 3.0% | 2.1% | 3.6% |
| **8.5 - 9.5** | 2.2% | 2.6% | 2.0% | 2.4% | 2.8% |
| **> 9.5** | 41.1% | 46.9% | 50.9% | 51.6% | 52.1% |
| **Total** | **100**% | **100**% | **100**% | **100**% | **100**% |

To demonstrate better, and scrutinise further, the relevant parts of Figure 3 and Figure 5 are superimposed onto one diagram in Figure 6, where the frequency of the time headways for vehicles in their next capture is shown by vertical bars, whereas the frequency of the time headways for all traffic (34,312 headways) without vehicle identification is shown by a curve. The categorisation of the headways in the legend of the figure as 'safe', 'unsafe', etc. is to give a rough idea about the driving behaviours. To give exact definitions for each category is outside the scope of the paper. Figure 6 highlights one of the most interesting findings of the study. As illustrated by the '*particular attention*' labels, more than half of the bar that is furthest to the left (with a dotted pattern) and a third of the next bar (with a grey pattern) in the 0.5-1.5 s category are above the 'generic' headway distribution curve (brought from Figure 3). Similarly, almost a third of the furthest left bar in the 1.5-2.5 s category is above this curve. These findings imply that the distribution of short headways of those drivers who had short headways in their previous capture is more skewed towards the left when compared with situations of longer headways. However, it is not so easy to suggest that those drivers who kept long headways in their previous capture tended to keep long headways in the next occurrence, although, to some extent, some of the bars in Figure 6 imply this.

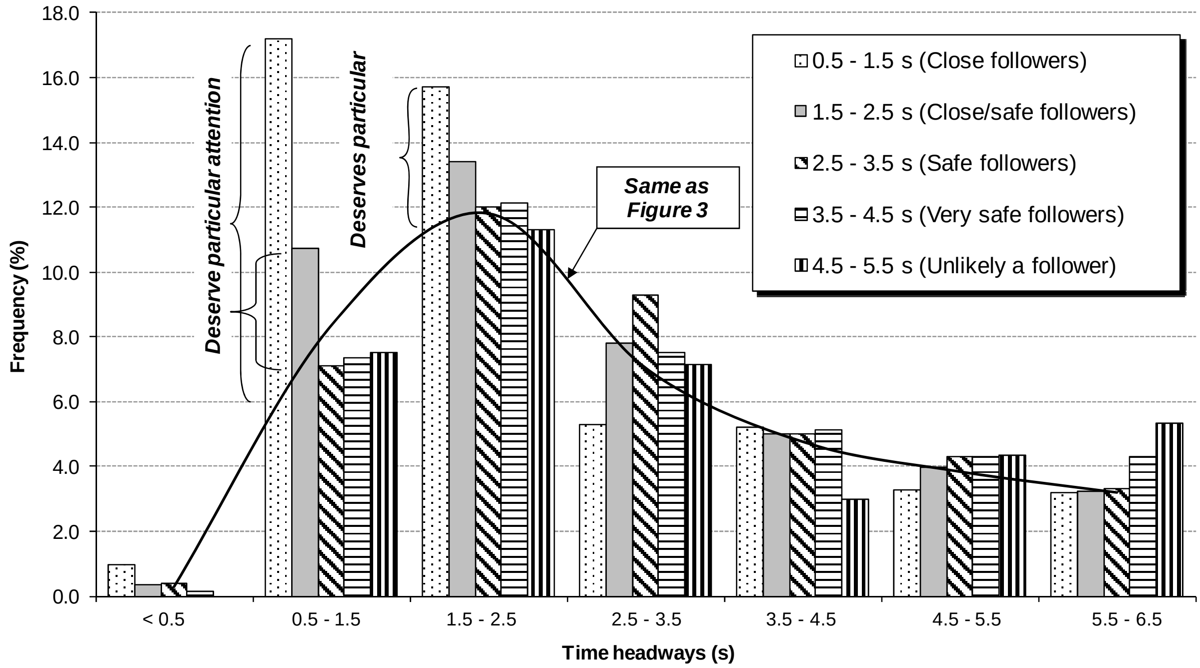


Figure 6: Close up of Figure 5 superimposed with Figure 3 (to aid clarity only the first seven intervals are shown on the *x* axis).

A similar analysis was carried out for the remaining (alternate) pairs. This time, while the first captures became the even number (2nd, 4th, 6th, etc.) captures, the next captures became the odd number (3rd, 5th, 7th, etc.) captures. Namely, the bars in Figure 7 contain all the headways in the:

2nd and 3rd captures of 4,214 vehicles (that are captured three times or more),
4th and 5th captures of 1,400 vehicles (that are captured five times or more),
6th and 7th captures of 578 vehicles (that are captured seven times or more), and so on.
Refer to Appendix B for the calculation of the above numbers of vehicles.

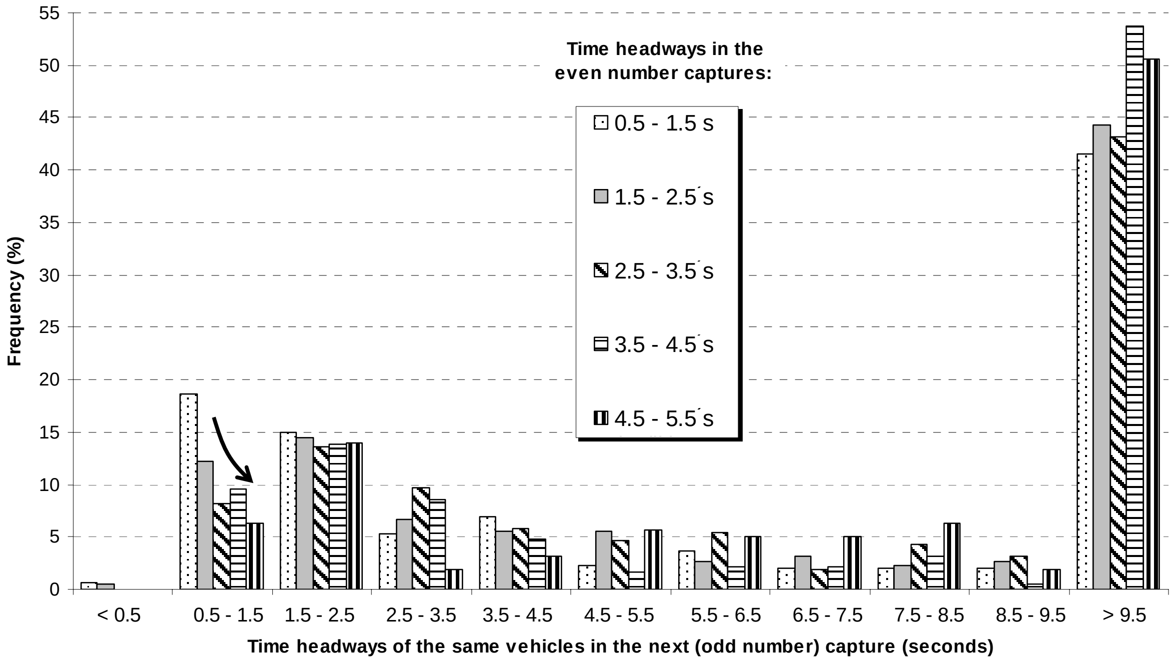


Figure 7: Frequency diagram of time headways for vehicles captured three times or more.

Again, for better illustration, the relevant parts of Figure 3 and Figure 7 are superimposed onto one diagram (Figure 8), where the frequency of the time headways for vehicles in their next capture is shown by vertical bars: the frequency of the time headways for all traffic (34,312 headways) without vehicle identification is shown by a curve. This figure, too, supports the above discussion that took place around Figure 6.

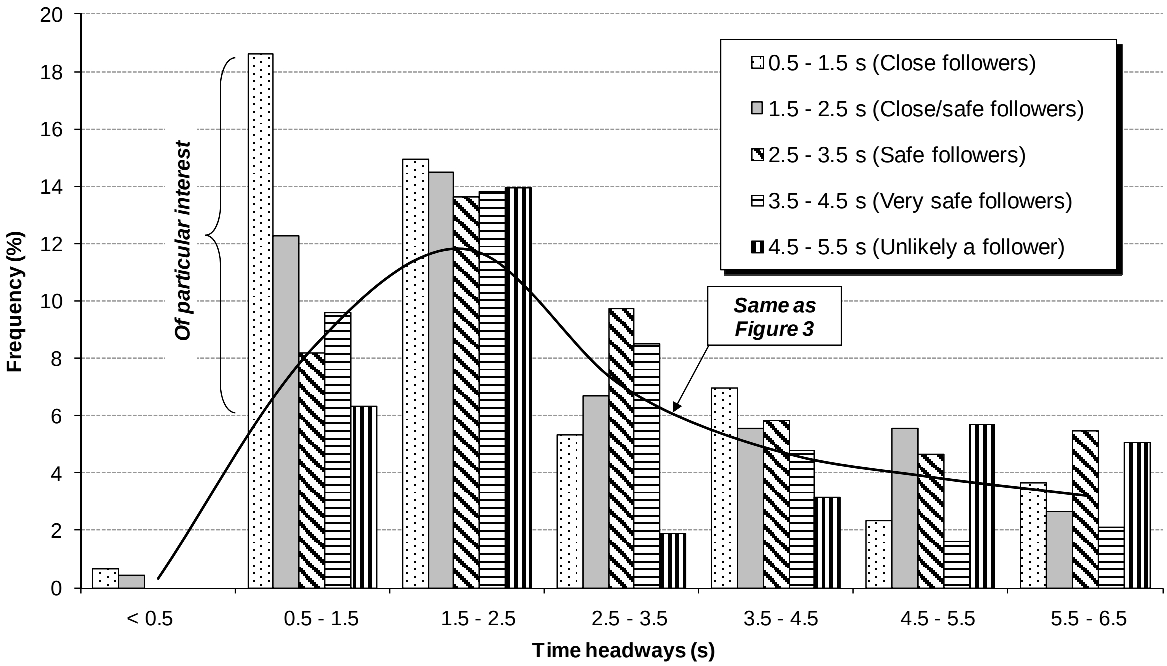


Figure 8: Close up of Figure 7 (to aid clarity only the first seven intervals are shown on the x axis).

# SPREAD OF HEADWAY PREFERENCES

In the next part of the data analysis, we looked at the mean and standard deviation (SD) values of time headways with particular reference to the same vehicles being captured more than once. We used the concept of SD to discuss the spread of headway values of the same vehicle over different captures. Table 5 demonstrates the arrangement of the data for this purpose. For example, the vehicle with the registration plate of '1346' was captured three times with headways of 3, 5, and 2 seconds respectively. These headway values are the time gaps between this vehicle and the preceding vehicle passed (not necessarily the same preceding vehicle at each capture, and not necessarily at three different sites). The mean and SD of these three headway readings for our subject vehicle were 3.33 and 1.528 respectively. The question now is to find if these mean and SD values imply any trend, since the three headway readings belong to the same vehicle (most probably the same driver). To address this question, we compared these SD values of randomly chosen headways from the entire data file without taking the vehicle identities into account. To do this, we generated 34,332 random numbers to pair with each of the actual registration plate readings. Then we sorted the whole data file with respect to this array of random numbers, which gave us a good shuffle of each line of the data grid. We then picked up every other headway (to be compared with the 'captured twice' vehicles) as shown in Figure 9.

Table 5: A part of the mean and SD file for illustration purposes

| Reg. Plate | Number of occurrences | Time headways (s) | | | | | *Mean (s)* | *SD (s)* |
|---|---|---|---|---|---|---|---|---|
| | | 1st capture | 2nd capture | 3rd capture | … | 18th capture | | |
| **1** | **9** | **5** | **12** | **3** | **…** | | *7.8* | *7.350* |
| **…** | **…** | **…** | **…** | **…** | **…** | **…** | … | … |
| **1345** | **18** | 5 | 2 | 7 | | 18 | *5.6* | *6.912* |
| **1346** | **3** | 3 | 5 | 2 | … | | *3.33* | *1.528* |
| **1347** | **2** | 2 | 1 | | | | *1.5* | *0.707* |
| **…** | **…** | **…** | **…** | **…** | **…** | **…** | … | … |
| **10024** | **3** | 8 | 2 | 12 | | | *7.33* | *5.033* |
| **Average of the means and SDs** | | | | | | | ***22.3*** | ***20.29*** |

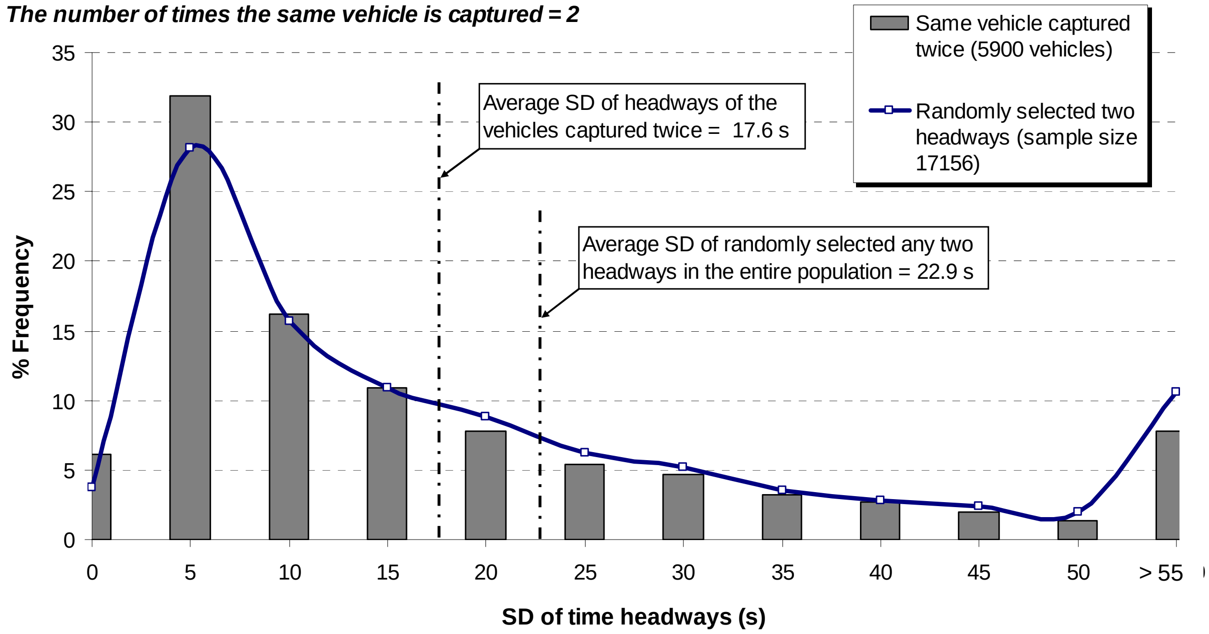


Figure 9: The distribution of the standard deviations of the time headways for the vehicles captured twice.

Similarly, we repeated the above steps to compare the SDs of headways of the 'captured four times' vehicles with the randomly picked every fourth headway from the whole population (Figure 10). Rather than doing the same analysis for every number of captures (from 2 to 18), we showed only 2 and 4 as a sample (with the highest number of readings, i.e. 5900 and 1938 headways). In both diagrams, a certain proportion (5% and 8%, respectively) of the 'SD = 5 second' bars were above the 'random SD' curve. The diagrams also show the difference between the average SDs between the 'same vehicle' headway readings and randomly picked 'any headway' readings. This, too, supports our earlier argument on the drivers' headway preferences issue.

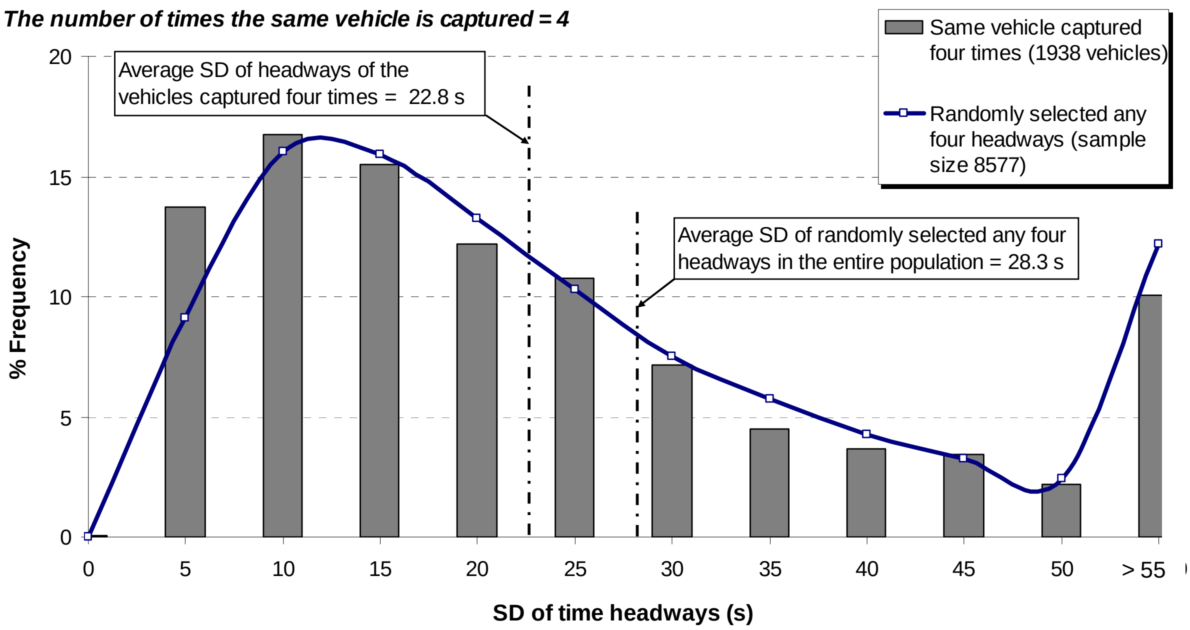


Figure 10: The distribution of the standard deviations of the time headways for the vehicles captured four times.

# CONCLUDING REMARKS

The paper developed a new method towards understanding close-following behaviour better, using a set of sample ANPR data. In light of the present paper, future research is expected to establish clear indications of headway preferences of individual drivers. Then, by means of information technology, it will become possible to contact and inform those drivers who, for example, close-follow consistently. Warning messages, such as "your vehicle was spotted so many times during this period at these locations" and "in so many percent of the time the time gaps between your vehicle and the vehicle in front were shorter than the recommended safe following value", could then be issued. Depending on the law, prosecution could even be considered for persistent offenders. There is, therefore, huge potential for further research in the field of measuring time headway preferences of drivers in a given time period using similar technologies.

There were limitations of the paper. For example, we looked at one day data for many sites. Future work may look at more number of days with fewer sites. Also, an interesting problem would be to know whether close-following tendency is affected by varying traffic conditions. For example, would drivers tend to close-follow more during congestion than they would do during free-flowing times? However, although it was possible to obtain flow information from the data, density (or occupancy) information was not available due to the nature of the data collection method. It should be remembered that, in a typical flow-density relationship (in the shape of an inverse horseshoe), there are two different density values corresponding to the same flow level. Any attempt to link close-following habit, revealed in Section 0, to flow (or volume) would be misleading, therefore. The investigation of this link is left for future work where loop detectors (for occupancy data) and the ANPR systems are employed simultaneously for data collection.

## ACKNOWLEDGMENT

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Appendix A: The calculation of the numbers of vehicles in relation to Figure 5 (originating from Table 2):

10,024 – (5,900 + 786) = 3,338
10,024 – (5,900 + 786 + 1,938 + 305) = 1,095
10,024 – (5,900 + 786 + 1,938 + 305 + 517 + 129) = 449
10,024 – (5,900 + 786 + 1,938 + 305 + 517 + 129 + 210 + 59) = 180

Appendix B: The calculation of the numbers of vehicles in relation to Figure 7 (originating from Table 2):

10,024 – 5,900 = 4,214
10,024 – (5,900 + 786 + 1,938) = 1,400
10,024 – (5,900 + 786 + 1,938 + 305 + 517) = 578