Estimation of critical occupancy values for UK motorways from traffic loop detectors

By: Jalal Al-Obaedi & Saad Yousif

Abstract

Occupancy is the percent of time a traffic loop detector embedded in the road pavement is occupied by vehicles. This term is usually used as a substitution for the traffic density which is not feasible to obtain from detectors. One of the recent applications for the traffic occupancy is in calculating the timing for traffic signals on motorway entrances (Ramp Metering, RM). Most of the existing algorithms for RM assume that these devices will not operate until the traffic occupancy upstream or downstream from the merge area exceeds a specific value called "critical occupancy". This paper focuses on estimating the critical occupancy using Motorway Incident Detection and Automatic Signalling (MIDAS) data. The data is taken from loop detectors located on three motorway sites in the UK. The results are compared with corresponding values as adopted by the Highways Agency for these sites to operate the ramp metering. The results show that the values which are currently used to operate the ramp metering devices in these sites are higher than those obtained from analysing the data. This will cause delays in the operation of the RM until the starting of traffic congestion which ultimately causes reduction in motorway capacity.

Keywords: Occupancy, loop detectors, ramp metering

1. Introduction and background

Occupancy is the percent of time a traffic loop detector embedded in the road pavement is occupied by vehicles. Unlike the well known traffic density, occupancy can easily be measured from traffic loop detectors that are located regularly around a motorway's junction. Hall *et. al* (1986) concluded that time occupancy can describe traffic conditions (congested, uncongested or transitional) in the same way as traffic density could do. Figure 1 explains the flow-occupancy relationship using data taken from an upstream detector from the M6 J23 Motorway site. The figure explains how this relationship is similar to that for flow-density. The relationship between traffic density and occupancy based on data from 5 detectors on the M6 J23 is presented in Figure 2. The density is estimated by dividing the motorway flow by the average speed.

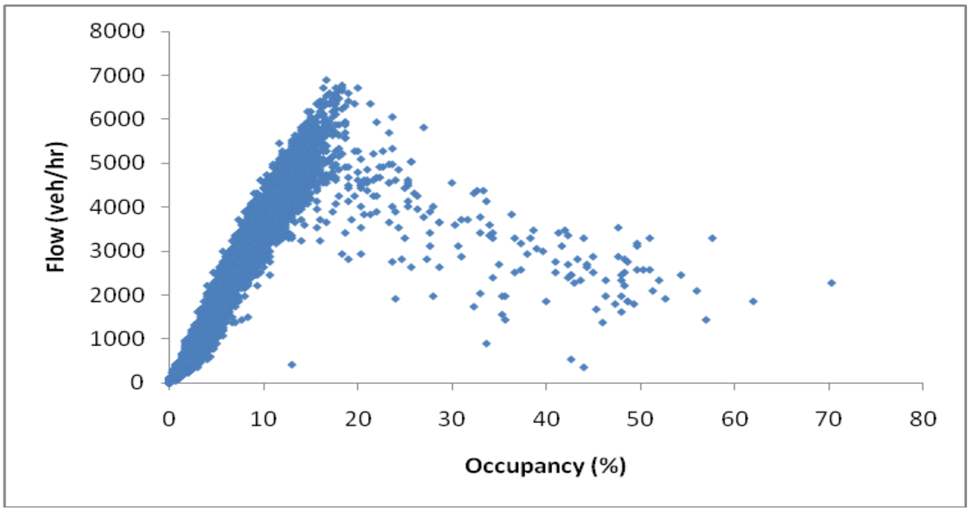

Figure 1 Flow-occupancy relationship bases on data from the M6 J23

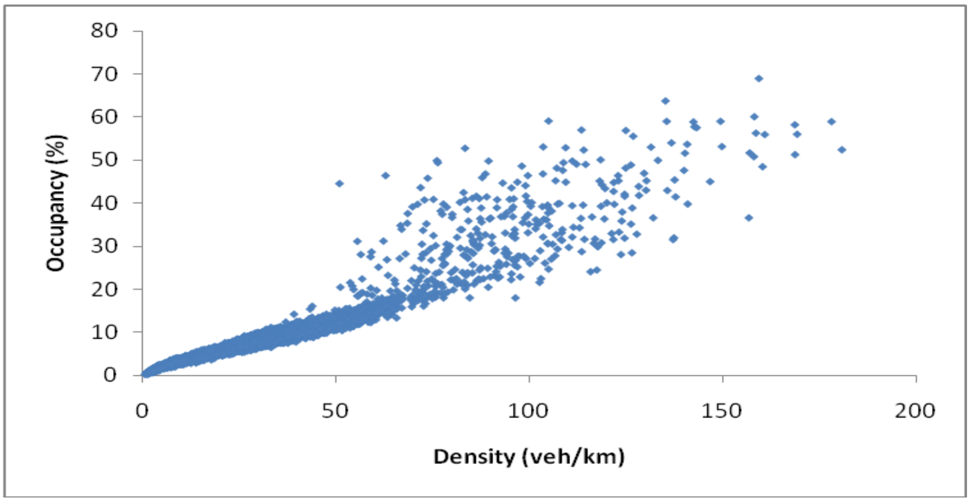

Figure 2 Occupancy-density relatioship based on data from the M6 J23

The term "Critical occupancy" is extensively used to define the limit between normal and congested traffic situations. In almost, critical occupancy corresponds with the motorway capacity Smaragdis et al. (2004). Previous research suggests a range of values for critical occupancy. For example, Hall *et al.* (1986) based on data from Queen Elizabeth Way in Ontario found that critical occupancy lies between 19 and 21%. The Minnesota Department of Transportation used a value of 18% to separate congested and uncongested flow. Sarintorn (2007) concluded that critical occupancy for the Pacific Motorway in Australia ranged from 17-20%. Zhang and Levinson (2010) used time occupancy to indicate the occurrence of bottlenecks using data taken from loop detectors in the USA. When the occupancy is less than 20%, traffic is regarded as not congested, when occupancy lies between 20 and 25% the traffic is regarded to be in the transitional phase while the traffic regarded to be in the congestion phase if the occupancy exceeds 25%.

2. Application of occupancy in ramp metering

Recently, traffic signal devices (ramp metering) have been installed on motorway entrances on a part-time basis to regulate the entering traffic in an attempt to reduce congestion. Previously, these devices worked on a fixed time plan where the traffic signal operated for specific periods with a set time. Now, most of existing methods for ramp metering are reactive. This means that the timing of the traffic signal changes based on the traffic conditions. In the later extension of ramp metering, time occupancy is applied in different ways. These are to judge the need to trigger the ramp metering devices, to calculate the required timing for traffic signal and finally to switch off the traffic signals after operating.

Currently, ALINEA (Papageorgiou et al., 1991, 1997) and Demand-Capacity algorithms (Masher et al., 1975) are the most applicable algorithms for ramp metering in the world. Both methods use occupancy in updating the traffic signal timing. ALINEA calculates the metering rate from equation 1 while Demand-Capacity uses equation 2.

$$r = r(c-1) + KR(Occ_d - Occ(c-1)) \qquad \text{... (1)}$$

$$r = \begin{cases} Cap - flow_{in} & if\ (Occ < Occ_{cr}) \\ r_{min} & else \end{cases} \qquad \text{....(2)}$$

Where:
r is the metering rate (veh/hr),
r(c-1) metering rate during the last time interval (veh/hr),
KR is the regulator parameter (veh/hr),
Occ_d is the desired occupancy and usually equal to critical occupancy (Occ_{cr}),
Occ(c-1) is the actual occupancy during the last time interval,
r_{min} is the minimum metering rate (veh/hr),
Cap is the capacity of the downstream merge section, and
$flow_{in}$ is the upstream motorway flow.

It is worth mentioning that using inaccurate values for critical occupancy can lead to the improper applications for ramp metering and that will affect the ability of these devices in the alleviation of traffic congestion. In addition, using values lower than the actual to trigger the traffic signals will cause further delays for merging traffic.

The contribution this paper is to estimate the critical values for critical occupancy using data from loop detectors and to compare these values with such values currently used on ramp metering on the studied motorways of the UK.

3. Methodology

In this paper, Motorway Incident Detection and Automatic Signalling (MIDAS) data from upstream and downstream loop detectors from 4 motorway sites is used. These sites are M56 J2 (two lanes), M60 J2 (three lanes), M6 J23 (three lanes) and M6 J20 (four lanes). The data provided is taken over one minute for speed, flow and occupancy.

Two methods are used to estimate the critical occupancy. The first method is suggested by Hall *et al.* (1986) for finding the average occupancy for each given flow. Obviously, there are two values of occupancy for each value of flow (i.e. in normal and congested traffic). The method requires an assumed trial value for critical occupancy. The purpose of that is not to average occupancies from normal conditions with those from congested conditions. After doing some trials for critical occupancy, all values then should be compared graphically. The critical occupancy value is then selected based on the point which gives the maximum flow at normal traffic condition. To apply this method the occupancy are averaged for each flows within interval of $\pm$100 veh/hr. A simple computer program is written to speed up the computational process. This method also requires the removal of the transition points from congested to normal conditions from consideration.

The second method is to inspect the raw data for values of occupancy which separate then normal and congested situations. This method is known as "time series inspection method". The method is mentioned by Hall et. al (1986) to explain the nature of changes in operations. However, they did not use this approach in estimating the critical occupancy. According to this method, critical occupancy will be the transition value from normal to congested situations.

The results from these three methods are compared in this paper by existing values which are currently in use to trigger the ramp metering in some of the above referred sites.

4. Results and discussions

Before applying the average occupancy approach for each corresponding flow, the data is filtered to remove the transition cases from congested to normal traffic situations. Figures 3, 4, 5 and 6 show the possible shapes for flow-occupancy relationships for different trials of critical occupancy values using the approach of average occupancy at each specific flow for the M56 J2, M6 J23, M6 J20 and M60 J2, respectively. For the M56 J2, Figure 3 shows that the critical occupancy value lies between 25 and 26%. Lower values are not considered because these lower values give flows for congested regime that are equal or higher to those in a normal regime. In the same way, and based on Figures 4-6, values of 23%, 22% and 20-21% are suggested for the M6 J23, M6 J20 and M60 J2, respectively.

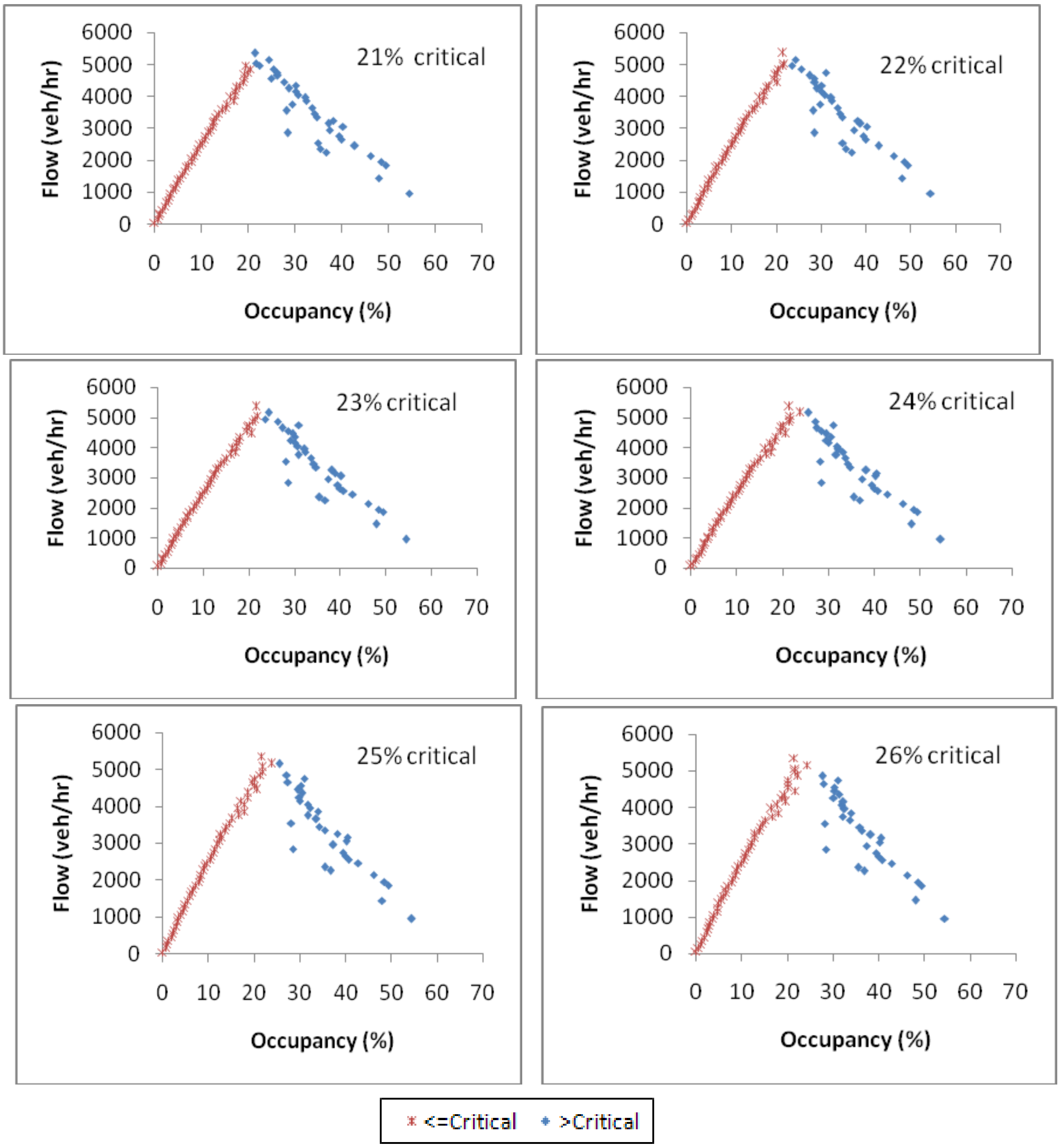

Figure (3) flow occupancy relationship for the M56 J2 downstream detector.

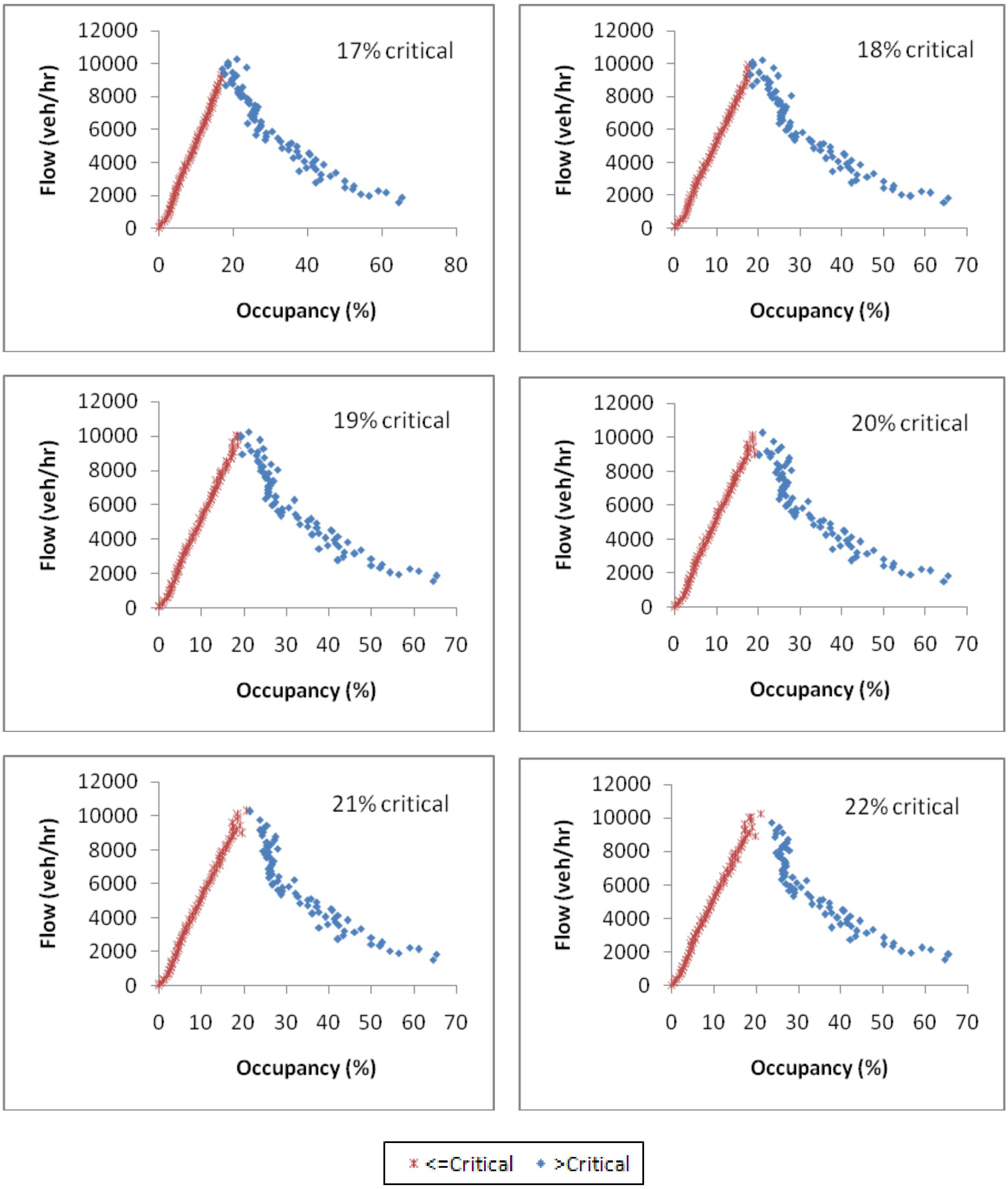

Figure (4) flow occupancy relationship for the M6 J20 downstream detector.

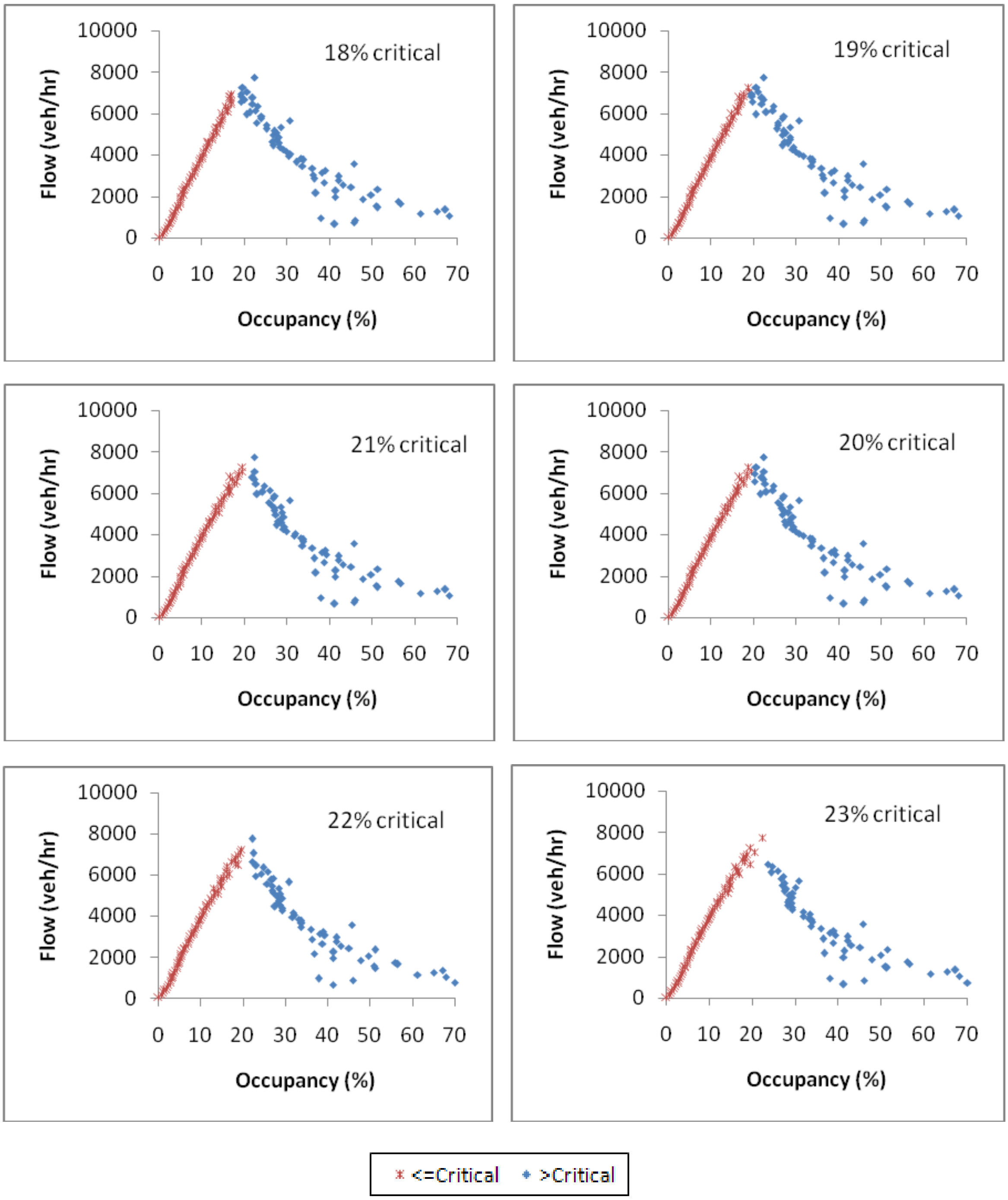

Figure (5) flow occupancy relationship for the M6 J23 downstream detector.

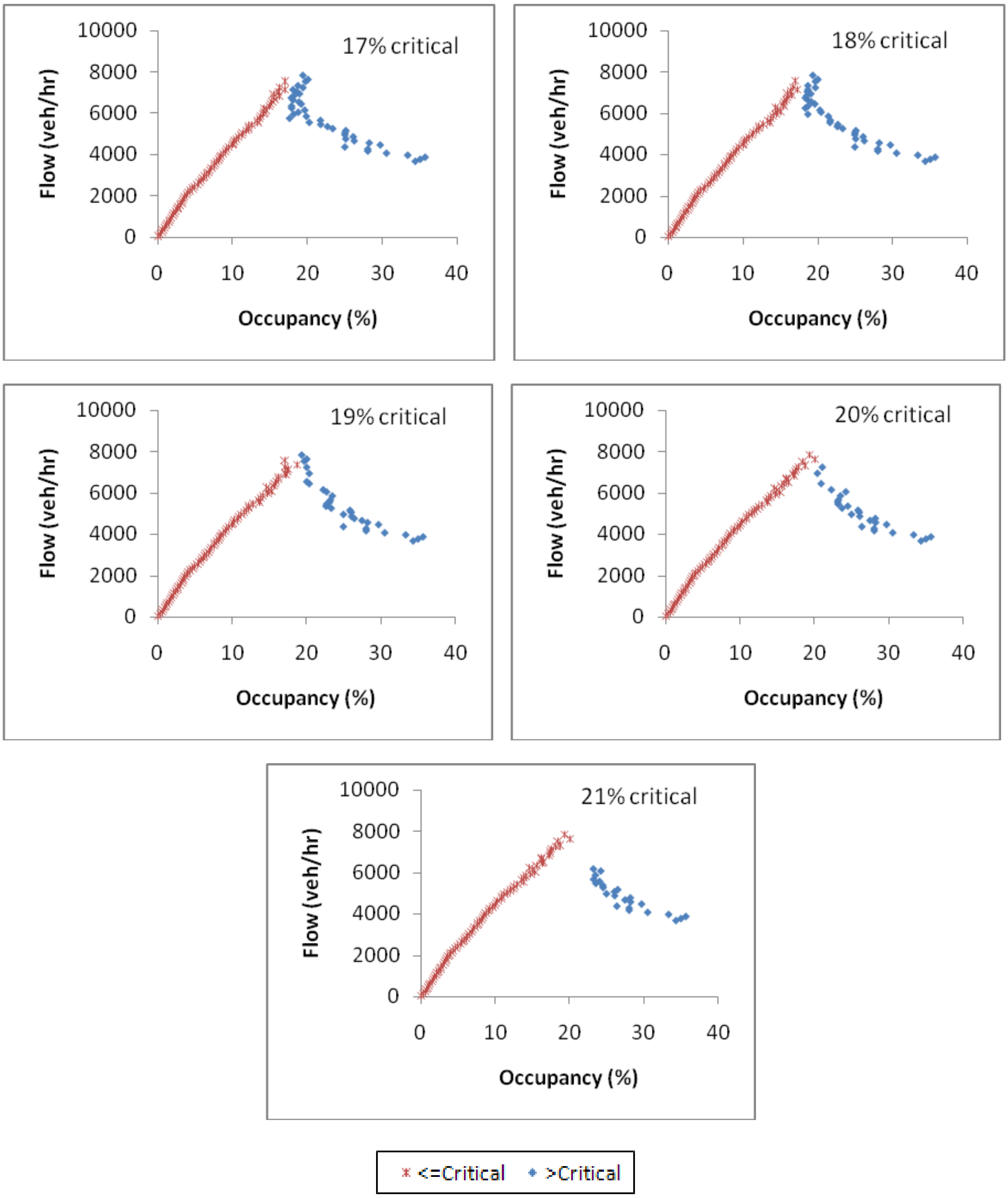

Figure 6 flow occupancy relationship for the M60 J2 downstream detector.

Figure 7 gives examples about critical occupancy values based on the time series inspection approach. It should be noted that only congested situations caused by merge traffic are considered (i.e. congested situations due to further downstream bottlenecks are not considered). While the results obtained from the first method (average occupancy) gave limited variation in critical occupancy between sites, the variation is more announced using the time series inspection method. This variation is also described in the work by Hall *et al.* (1986).

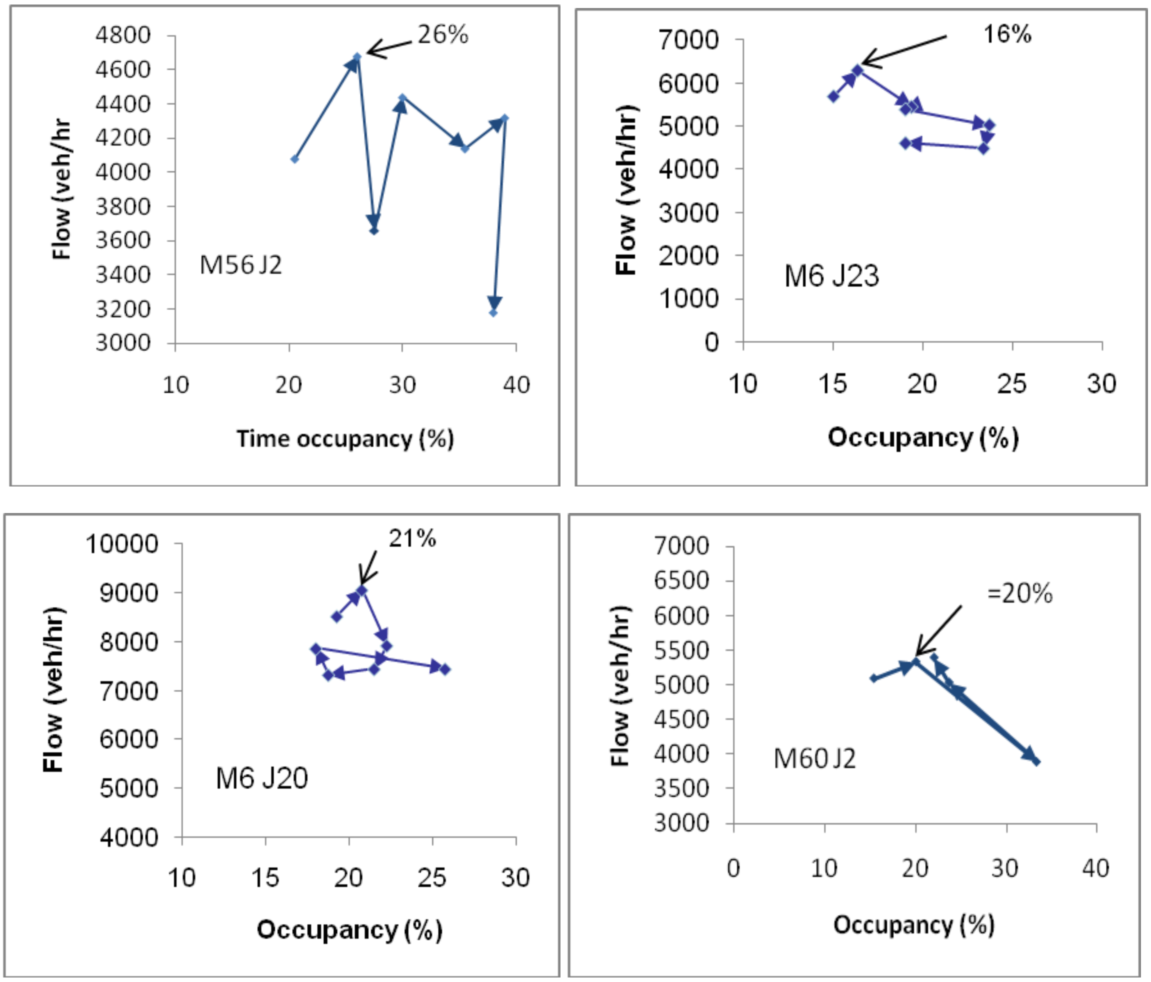

Figure 7 Critical occupancy values using time series inspection method

Table 1 compares the critical occupancy values obtained from the average occupancy approach with such critical values that are currently in use to trigger the ramp metering devices on the selected motorway sites. The value that is used to trigger the ramp metering in M56 J2 was not given due to a lack of data. The table shows that for the M6 J23 and M6 J20 sites, the values which are currently used to operate the ramp metering devices in these sites are higher than those obtained from analysing the data. This will cause delays in the operation of the RM after the traffic congestion has started and that ultimately causes reduction in motorway throughput. For the M60 J2, the value used is much close to the estimated value.

Table 1 Estimated and Values in use for critical occupancy

Site	M6 J23	M6 J20	M60 J2
Estimated critical occupancy (%)	23	22	20-21
Value in use in RM (%)	28	25.5	19

5. Summary

This paper focuses on the estimation of critical occupancy using data taken from loop detectors. The data from four motorways junctions which are served by ramp metering devices in the UK are used. These motorways are M56 J2, M60 J2, M6 J23 and M6 J20. Two methods are used to find the critical occupancy. The first method is by finding the average occupancy for each corresponding flow. The second method is to follow-up the transitions from normal to congested situations. It is found that the variation between the results between the selected sites is more pronounced using the second method. The results are compared with corresponding values as adopted by the Highways Agency for these sites to operate the ramp metering. As a part of M60 J2, the results show that the values which are currently used to operate the ramp metering devices in these sites are higher than those obtained from analysing the data. This will cause delays in the operation of the RM until the starting of traffic congestion which ultimately causes reduction in motorway capacity.

6. References

Hall, F. L., Allen, B. L. and Gunter, M. A., (1986). Epirical analyses of freeway flow-density relatioships. Transportation Research A, Vol. 20A, No. 3 p.p. 197-210.

Masher D.P., Ross D.W., Wong P.J., Tuan P.L., Zeidler H.M., and Petracek S., (1975), Guidelines for Design and Operation of Ramp Control Systems", Stanford Research Institute, Menid Park, CA.

Minnesota Department of Transportation, (2000). MnDOT Traffic Management Center all detector report

Papageorgiou, M., Haj-Salem, H. and Blosseville, J-M. (1991). "ALINEA: a local feedback control law for on-ramp metering." Transportation Research Record, Volume (1320), p.p. 58-64.

Papageorgiou, M., Haj-Salem, and F. Middleham, (1997), ALINEA local ramp metering: Summary of field results. In Transportation Research Record 1603, TRB, National Research Council, Washington D.C., 1997, pp. 90-98.

Sarintorn, W. (2007) Development and comparative evaluation of ramp metering algorithms using microscopic traffic simulation. Journal of Transportation, Volume (7), Issue 5, p.p. 51-62.

Smaragdis, E., Papageorgiou, M. and Kosmatopoulos, E. (2004) A flow-maximizing adaptive local ramp metering strategy, Transportation Research Part B: Methodological, Volume (38), Issue 3, p.p. 251-270

Zhang, L. and Levinson, D. (2010) Ramp metering and freeway bottleneck capacity Transportation Research Part A 44 218–235.