

Transport Research & Information Note

A Study of Lane Capacity in the Greater Dublin Area

February 2012



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1. Overview

- 1.1. In February 2011, the NRA Traffic Management Study set out a series of concepts and solutions for management of traffic flow on the National Road Network. The Study referenced the definition of Management Alternatives in the Common Appraisal Framework, inter alia;

“...seek to respond to transportation problems by maximising the value of existing infrastructure.”

- 1.2. The Traffic Management Study examined a range of fiscal and control solutions for application on National Roads. Within this architecture of solutions, Traffic Control measures were presented as a means of managing traffic streams to improve safety, capacity and efficiency at levels of traffic flow which were approaching or exceeding the theoretical capacity of a road.
- 1.3. In the design and appraisal of such measures, it became clear that there is limited existing guidance on the capacity of traffic streams, and hence an understanding of the point at which such measures should be considered.
- 1.4. The planning of capacity enhancements on National Roads has for many years referred to TD9¹, which prescribes various road types based on the Annual Average Daily Traffic (AADT) that is forecast along a road within a specific horizon. This approach, however, presents two major shortcomings as follows:
- It does not account for the traffic flow profile that comprises AADT, and how traffic flow presents defined peaks and troughs during a typical day; and
 - It does not take into account the capabilities of Traffic Control in increasing the efficiency of traffic streams.
- 1.5. This Paper examines traffic behaviour on key National Primary Roads in the Greater Dublin Area. It seeks to understand the actual capacity of a lane, and attempts to relate this to *Level of Service* as set out in the US Highway Capacity Manual (the original source for the Level of Service concept).
- 1.6. The analysis is undertaken through the construction of lane-based speed flow curves at a sample of locations to understand the flow levels which define the capacity of a traffic stream. Practical capacity limits are identified for the existing layout, and flow cut-offs are defined above which traffic control solutions are warranted.

2. Literature Review

- 2.1. There is good availability on the study of traffic streams, and the measurement of lane capacity. Common throughout the academic evidence is a number of basic assertions, namely that mainline capacity is dependent on the level of ‘turbulence’ in a traffic stream. It was common for research to report lane capacities well in excess of 2,000 vehicles per hour.

¹ TD9/07, NRA Design Manual for Roads and Bridges, Volume 6, Section 1

- 2.2. Nevertheless, the research continuously suggests that this lane capacity decreases substantially during flow breakdown events. In such cases, the emergence of a bottleneck is as a direct result of a breakdown event, and leads to ongoing congestion until the upstream flow reduces below the bottleneck capacity. The basis for Traffic Control is therefore the retention of laminar traffic flow conditions such that breakdown, and the consequential capacity reduction, can be avoided.

TRL Report titled "A study of traffic capacity through the various features of highway roadworks" published in 1991 by Hunt, Griffiths, Moses and Yousif

- 2.3. The report outlines the collection and collation of traffic information from 27 sites throughout the U.K. The study found that *"In the absence of incidents flow breakdown was found in the traffic flow range of 1600 to 2300 pcu/h/lane"* whilst the *"average sustainable flow was found to be 4050 pcu/h for a 2 lane section which does not include a hard shoulder, and 3900 pcu/h for a 2 lane section including a hard shoulder"*. The study also *"identified the merge area as the primary source of congestion induced by excess demand flow. Under heavy flow conditions forced merging from the closed lane served to initiate and propagate flow breakdown similar to that observed on highway sections downstream of entries from intersections"*. Overall, lane capacity was found to be in the region of 1,950 – 2,025 pcu/hr/lane.

Transportation Research Board paper "Capacity Estimation for Two Lane Two-Way Highways using Simulation" published in 2007 by Kim and Elefteriadou.

- 2.4. The paper stated that *"The Highway Capacity Manual 2000 (HCM 2000) indicates that the capacity of two-lane, two-way highways is 1,700 pcph for a single direction and 3,400 pcph for both directions. The paper found that the "capacity of two-lane, two-way highways under base conditions is found to range from 1,800 pcph to 2,100 pcph as a function of average free flow speed. The presence of passing zones was not found to have an effect on capacity. When a driveway or horizontal curve or upgrade is present, the capacity reduction ranges between 3 and 30 percent when there are no trucks, and may reach up to 40 percent when trucks are present in the traffic stream."* Overall, lane capacity was found to be in the region of 1,700 – 2,100 pcu/hr/lane.

"The marginal decrease of lane capacity with the number of lanes on highway" published in 2005 by Yang and Zhang of Beihang University, Beijing.

- 2.5. The paper investigates the impact the number of lanes on a highway has on capacity based on extensive field surveys undertaken in Beijing. The surveys were undertaken over a week on a number of roads with varying numbers of lanes. The paper states that in Japan and China the highway manuals prescribe that *"average capacity per lane on uninterrupted multilane highway is 2200 pcu regardless of the number of lanes"*. The paper then outlines the outcome of the field surveys which were undertaken on two, three and four lane highways. An assessment of the surveys found that the *"average capacity per lane on a highway with two, three or four lanes is 2,104, 1,973 and 1,848 pcu respectively"* as shown in the graph extracted from the paper below.

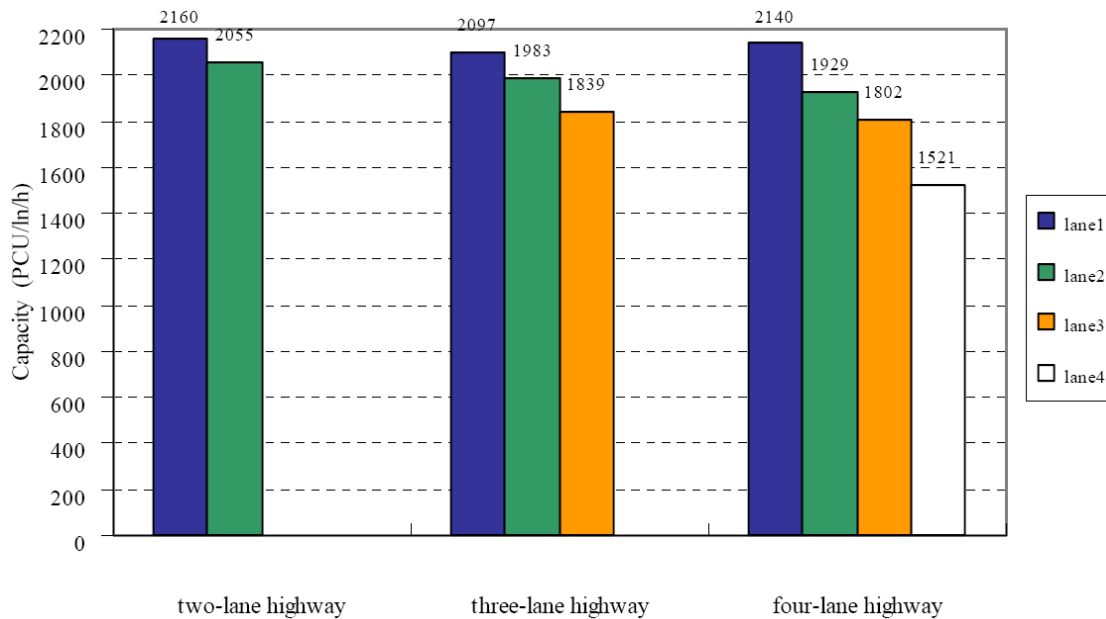


Figure 2.1: Capacity of highways based on number of lanes (Yang and Zhang, 2005)

2.6. The above capacities are based on highways in Beijing and therefore may not be appropriate for use on Irish roads however the report also outlined that “the marginal decrease rate of average capacity per lane with increasing numbers of lanes is around 6.7% per lane” which could be applied to capacities appropriate to Ireland to account for differing lane numbers.

“Traffic Flow Analysis Beyond Traditional Methods” published by Werner Brilon from Ruhr-University Bochum, Germany.

2.7. This paper introduces the idea of the efficiency of a road and its relationship with road capacity. Figure 2.2 below shows E (Efficiency) as a function of q (Flow) for a highway section (shown in blue) in comparison to the speed-flow curve (shown in red below). The figure below applies to a basic three-lane highway segment with a free flow speed of 120 km/h, taken from the HCM (2000) Highway Capacity Manual.

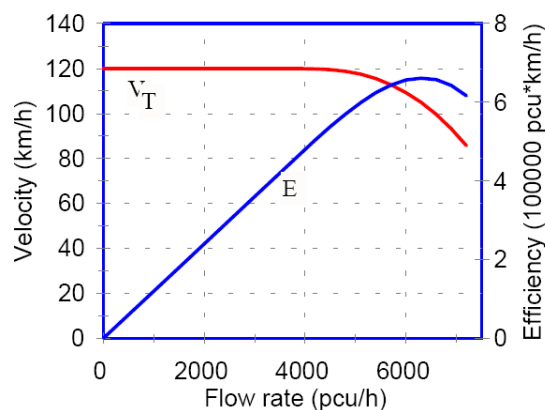


Figure 2.2: Efficiency of the speed-flow relationship (Source: Brilon)

2.8. As can be seen in above the efficiency reaches its maximum at a flow rate of nearly 0.9 times the capacity. It can be derived from the figure above the optimum flow rate in terms of speed and efficiency is in the region of 5,800 – 6,200 pcu/hr for a three lane highway equating to 1,930 – 2,070 pcu/hr/lane.

“A Probabilistic Approach to Defining Highway Capacity and Breakdown” published by Lorenz and Elefteriadou from the “Pennsylvania Transportation Institute, Pennsylvania State University, USA.

2.9. This paper addresses the need for an enhanced highway capacity definition that incorporates the probabilistic nature of the highway breakdown process. It consists of an extensive analysis of speed and volume data collected at two highway bottleneck sites in Toronto, Canada.

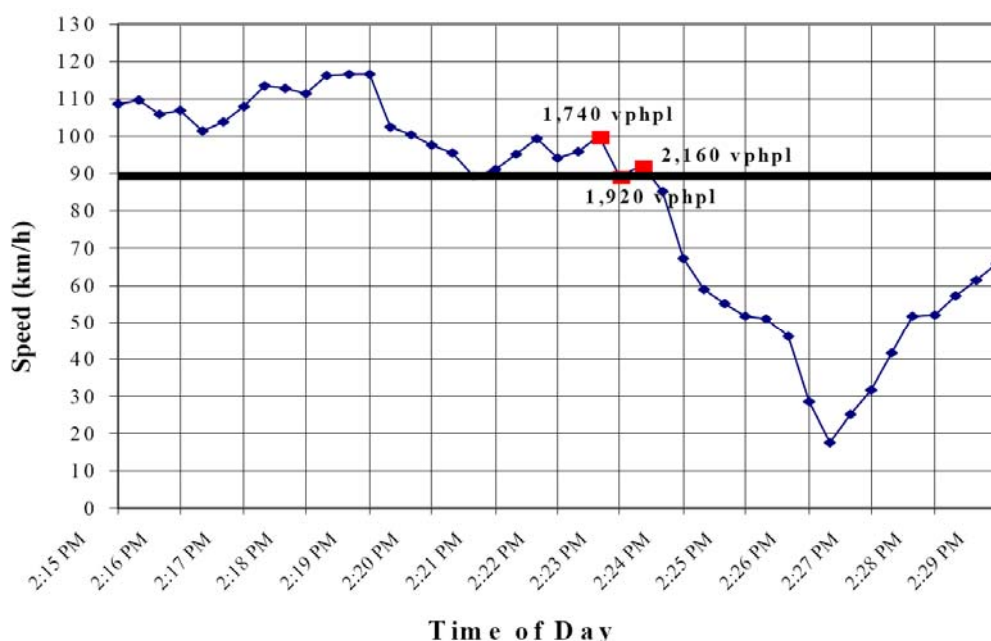


Figure 2.3: Speed and Flow plot during breakdown conditions (Source: Lorenz and Elefteriadou)

2.10. The paper found that ‘following an examination of time-series speed plots, similar to Figure 2.3 above, it was evident that a speed “boundary” or “threshold” of approximately 90 km/h exists between the congested and uncongested regions at this location. When the highway operates in an uncongested state, average speeds across all lanes generally remain above the 90 km/h threshold at all times. Conversely, during congested conditions, average speeds rarely exceeded 90 km/h, and even then were not maintained for any substantial length of time. This 90 km/h threshold was observed to occur at both study sites and in all of the daily data samples evaluated as part of the research. It should also be noted that this threshold is a close approximation of the 85 km/h speed threshold for level-of-service “F” denoted in the 1997 Highway Capacity Manual(HCM).

2.11. The paper defined the “breakdown flow rate” as ‘the flow rate per lane observed immediately prior to breakdown. However, a breakdown flow rate value determined

for a single breakdown event at a particular site merely represents one of many possible breakdown flow rate values for that site. Additional flow rate values associated with other breakdown events at that site (on the same day and on other days) need to be determined as well. Furthermore, the breakdown flow rate values need to be compared to equivalent flow rates observed at times when breakdown did not occur. Therefore, for each site, the model describing the probability of breakdown is determined by comparing: 1. the frequency of breakdown at a given flow rate, with 2. the number of times breakdown did not occur at that given flow rate, and plotting the results over the range of flow rates observed at the site. Assuming a typical highway bottleneck breaks down only once or twice on a given weekday (usually during the morning or evening peak period, or both), it is apparent that a large quantity of data, spanning many breakdown periods, is required to estimate the probability of breakdown for any bottleneck site. For this paper, over 40 breakdown events were investigated at each site’.

- 2.12. The figure below sets out the results outlined in the paper. As can be seen from below, if a flow rate of 1850 vehs/lane/hr is maintained for 1 minute the probability of breakdown is very low (~1%) however if it is maintained for 5 to 15 minutes the probability increases to 19 - 47%.

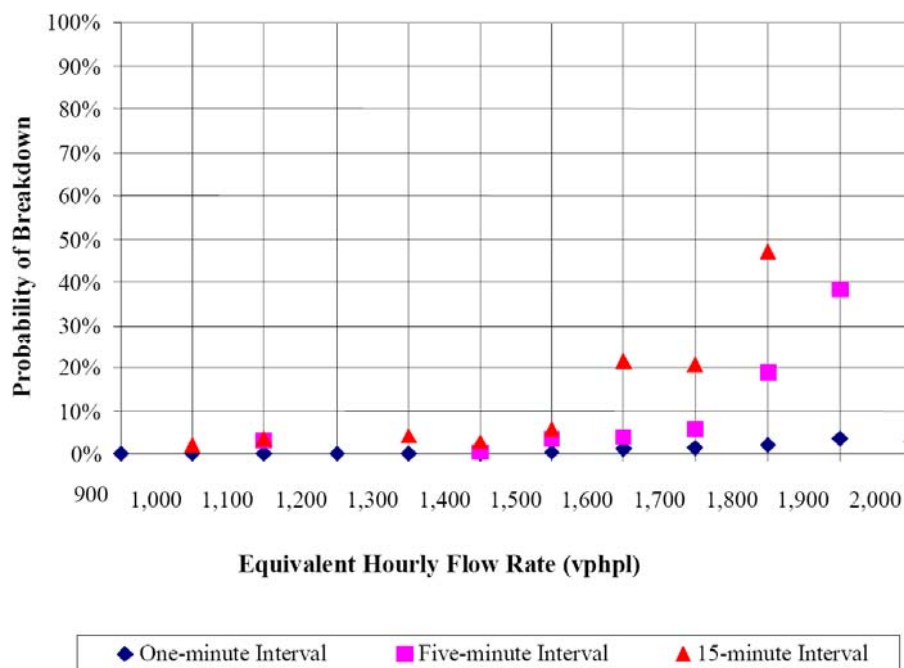


Figure 2.4: Probability of breakdown at different flow rates (Source: Lorenz and Elefteriadou)

- 2.13. As set out in the paper, ‘the traffic stream is capable of absorbing brief fluctuations in the flow rate, even those above 2,000 vphpl, without resulting in a high risk of breakdown. This is because the 2,000-vphpl rate is only sustained over a short period (one minute). On the other hand, if the aggregation interval is increased to five minutes, the breakdown probability for 2,000 vphpl is substantially higher because the rate is sustained over a much longer time period. Similarly, the 15-minute interval has the highest probability of breakdown for a given flow rate’.

“Traffic Flow Theory” published on behalf of US Department of Transport by the Federal Highway Administration and Oak Ridge National Laboratory, USA (1992).

- 2.14. This paper investigates previous work undertaken regarding the speed – flow relationship. As outlined in the paper *‘the bulk of the recent empirical work on the relationship between speed and flow (as well as the other relationships) was summarised in a paper by Hall, Hurdle, and Banks (1992). In it they proposed the speed flow model for traffic flow shown in Figure 2.5.*

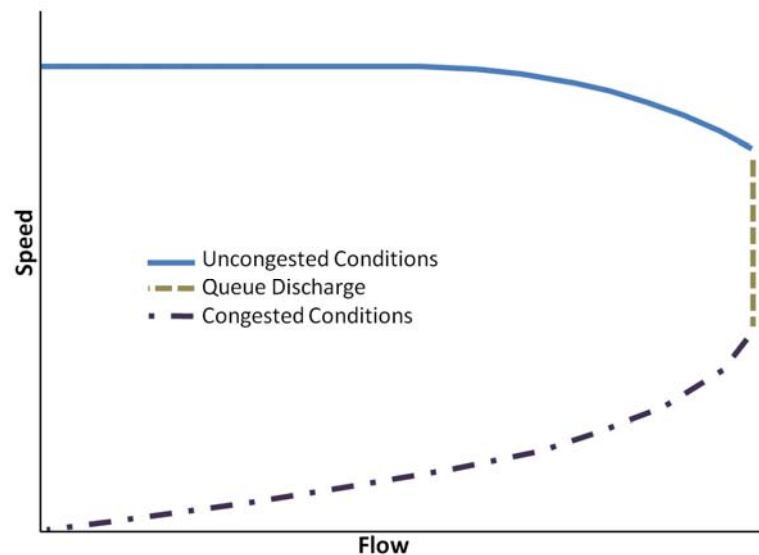


Figure 2.5: Generalised shape of a speed-flow relationship curve

- 2.15. *Additional empirical work dealing with the speed-flow relationship was conducted by Banks (1989, 1990), Hall and Hall (1990), Chin and May (1991), Wemple, Morris and May (1991), Agyemang-Duah and Hall (1991) and Ringert and Urbanik (1993). All of these studies supported the idea that speeds remain nearly constant even at quite high flow rates.*
- 2.16. *Two elements of these curves were assumed to depend on free-flow speed: the breakpoints at which speeds started to decrease from free-flow, and the speeds at capacity. Although these aspects of the curve were only assumed at the time that the curves were proposed and adopted, they have since received some confirmation in a paper by Hall and Brilon (1994), which makes use of German Autobahn information, and another paper by Hall and Montgomery (1993) drawing on British experience.’*
- 2.17. Historically speed flow curves which have been developed as part of guidelines, e.g. COBA guidelines, are based on robust data for the free flow rate however following breakdown little information is available and the form of the curves following breakdown are based on assumptions. The figure below is an example of this where the speed – flow relationship during uncongested conditions is based on empirical data the relationship following breakdown is based on assumptions.

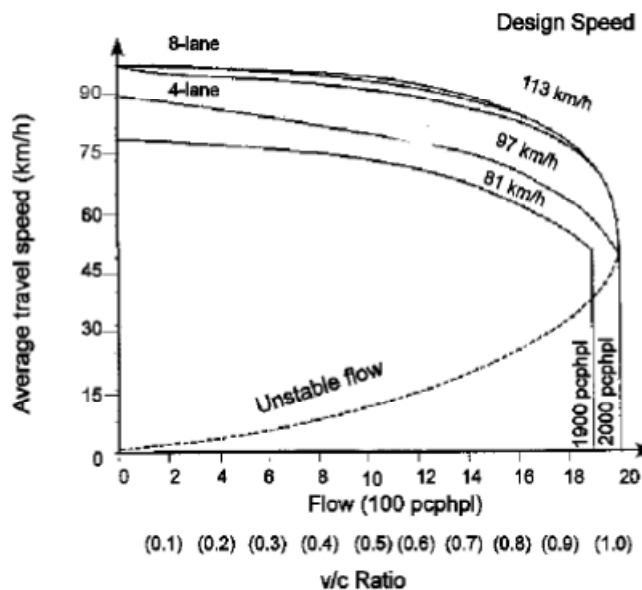


Figure 2.6: Speed-flow relationship curve based on empirical data (HCM, 1985)

- 2.18. The paper goes on to discuss the evolution of the Speed-Flow Relationship over the years as outlined below, “At present, several aspects of the speed-flow model have been verified by different studies. First, freeflow speeds are maintained until just before the capacity is reached. The decreasing slope of the model at free-flow speed has been a consistent trend, where speeds now remain constant as the flow rate increases, until around half or two-thirds of capacity values (3). Secondly, the flow rate at which capacity is reached has increased from Greenshield’s (5) 1,800 passenger cars per hour per lane to the 2,200 passenger cars per hour per lane shown in the 2000 HCM. Finally, a set of curves have been created to account for differing free-flow speeds, also depicted in the 2000 HCM. The flow rates at which speeds begin to decrease from free-flow, and the speeds at capacity, have been verified by other studies (3). These accepted speed-flow characteristics are telltale indications that a particular data set is behaving as expected under normal, uninterrupted flow conditions. Although the speed flow model has been improved significantly over the years, uncertainties still exist. The 1985 and 1965 HCM both show the lower half of the curves, however in the 1994 edition only the top portion of the model is depicted because flow conditions in the lower half of the curve are so unstable. Even though the 1994 and 2000 Highway Capacity Manuals do not specify the shape of curve after capacity is reached, field data from previous research show that the lower half of the speed-flow relationship curves back around so that as flow rates decrease, the speed also decreases as seen in earlier HCM models. “

3. Published Ranges in Lane Capacity

- 3.1. The various research studies have therefore outlined a range of lane capacities under different conditions. Bearing in mind that there is no common definition of lane capacity itself, there still would appear to be a broad consensus that the capacity of a lane is in the region of 1,700 to 2,100 passenger car units per hour. The actual value for any site will depend on the mix and age of the vehicle fleet, weather conditions, familiarity with driving on major roads, the level of weaving within the traffic stream, and gradient.

- 3.2. Whilst much of the discussion above has related to the theoretical capacity of traffic lanes, this paper will use the term 'Practical Capacity'. Practical capacity will refer to that point at which flow breakdown events will start to occur within the traffic stream. This is distinct from Theoretical Capacity, which defines the maximum traffic flow in a lane, regardless of the traffic conditions. Both Practical and Theoretical Capacity can be represented in Passenger Car Units per Hour.
- 3.3. In this regard, Traffic Control Measures are those which seek to increase the Practical Capacity closer to the Theoretical Capacity through the reduction of Flow Breakdown events at the lower flow ranges. Traffic Control Measures cannot impact on the Theoretical Capacity of a traffic lane.

4. Data Collection

- 4.1. In order to determine the Practical Capacity for roads in the Greater Dublin Area, traffic speed and flow information was required on a lane-by-lane basis across a sample of sites. This construction of speed flow curves would allow mapping of breakdown events and hence the identification of the Practical and Theoretical Capacity of each lane.
- 4.2. Prior to collecting such information, it was necessary to identify sites where traffic streams were not adversely affected by downstream congestion, traffic management works, incidents and any other conditions which and make it more susceptible to breakdown. In circumstances where traffic management measures are in place on road links for a significant period of time, such sites were not precluded from the data collection exercise but were subject to an additional data cleaning exercise.
- 4.3. Following the initial screening exercise, a number of suitable sites on the M50, M11 and M1 were identified in consultation with the NRA. At each site, surveys collected information on mean speed and total traffic flow at 1-minute intervals across the peak periods. The locations of the surveys are shown in Figure 4.1.

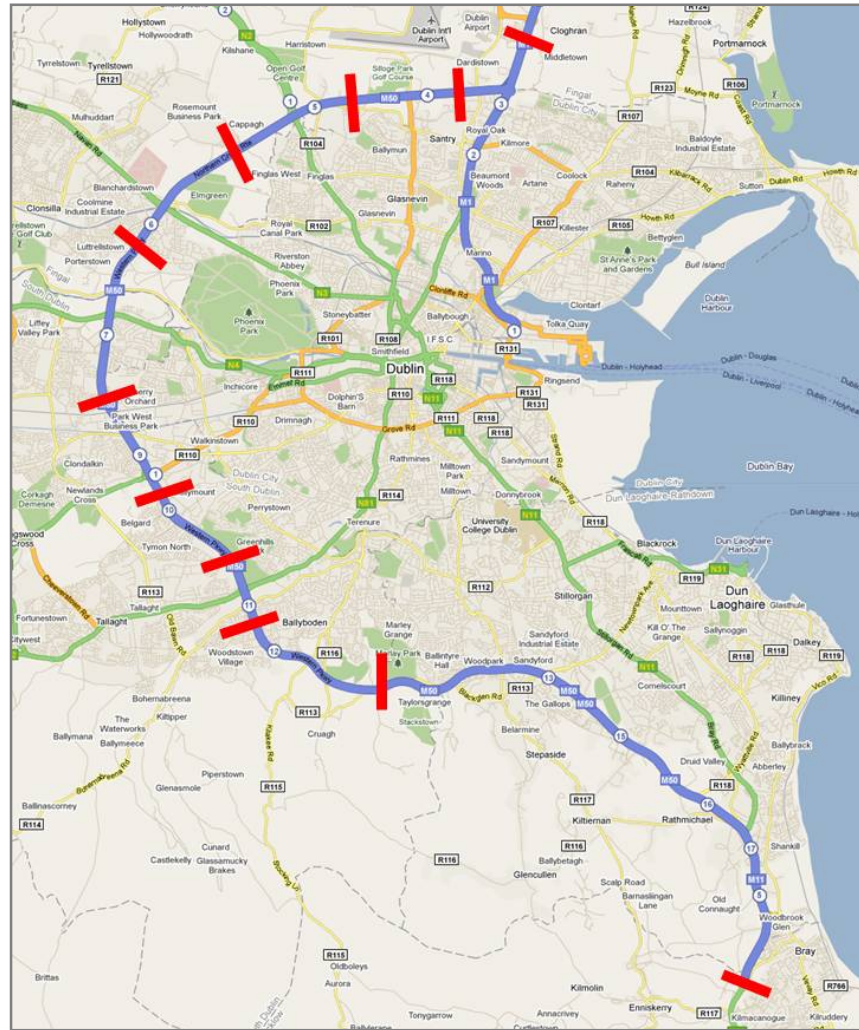


Figure 4.1: Location of Speed/Flow Surveys

4.4. Following collation of the survey results, a further screening exercise was undertaken which used the results of the surveys to understand the factors leading to breakdown. In those cases where breakdown occurred at very low traffic flows, where there were obvious downstream blockages, these sites were removed from the dataset. A summary of this process and of the final sites selected is outlined in Tables 4.1 and 4.2.

Table 4.1: Screening of Survey Sites – M50

M50 Section	Traffic Volume Available?	Speed Survey Available?	Notes	Suitable?
M1 - BMN	✓	✓	Traffic Management in place Northbound	✗
BMN - N2	✓	✓	Conditions unsuitable	✗
N2 - N3	✓	✓	-	✓
N3 - N4	✓	✓	Conditions unsuitable	✗
N4 - N7	✓	✓	Conditions unsuitable	✗
N7 - BMT	✓	✓	-	✓
BMT - N81	✓	✓	-	✓
N81 - FIH	✓	✓	Some Traffic Management in place	✓
FIH - BAT	✓	✓	Conditions Unsuitable	✗
BAT - SAF	✓	✗	Conditions Unsuitable	✗
SAF - LEP	✓	✗	Conditions Unsuitable	✗
CAM - CHW	✓	✗	Conditions Unsuitable	✗
CHW – N11	✓	✓	-	✓

Table 4.2: Screening of Survey Sites – Radial Routes

Section	Traffic Volume Available?	Speed Survey Available?	Notes	Suitable?
N11 at Fassaroe	✓	✓	-	✓
M1 Airport North	✓	✓	-	✓
N3 at Dunshaughlin	✓	✓	Location impacted by external influences, junction in close proximity	✗
N2 at Coldwinters	✓	✓	Location impacted by external influences, junction in close proximity	✗
N4 at Maynooth	✓	✓	Location impacted by external influences, junction in close proximity	✗

5. Plotting Speed Flow Curves

- 5.1. The speed – flow relationship was derived for each site by plotting the average speed (recorded each minute) against the total flow (vehicles per minute) for each of the suitable sites. A speed flow curve was therefore developed for twelve individual links which experience some level of flow breakdown during the survey period. The location of the links used in the generation of the speed flow curves are outlined in Table 5.1 below.

Table 5.1: Speed Flow Curve Locations

Location/Lane/Time Period	Traffic Flow per Minute		Equivalent Hourly Flow	
	Min	Max	Min	Max
M1 Southbound - Inside - AM	19	39	1140	2340
M1 Southbound - Outside - AM	24	44	1440	2640
M50 South of Junction 11 Northbound - Inside - AM	12	36	720	2160
M50 South of Junction 11 Southbound - Inside - AM	6	32	360	1920
M50 South of Junction 11 Southbound - Outside - AM	6	44	360	2640
N11 Southbound - Outside - PM	24	40	1440	2400
N11 Southbound - Inside - PM	17	32	1020	1920
M50 South of Junction 17 Southbound - Middle - PM	8	31	480	1860
M50 South of Junction 5 Northbound - Inside - PM	4	28	240	1680
M50 South of Junction 5 Northbound - Middle - PM	17	35	1020	2100
M50 South of Junction 5 Northbound - Outside - PM	18	39	1080	2340

- 5.2. As can be seen above the maximum flows on the above links vary from 1,680 – 2,640 which highlights the variability of the flow at which breakdown occurs.
- 5.3. As a final screening of data, it was necessary to remove those sites where there was no transition into turbulent flow and/or flow breakdown during the survey period. For the sites outlined below in Figures 5.1 and 5.2, traffic speeds remained between 60kph and 100kph at all levels of traffic flow. This suggests that flow was metered by a downstream bottleneck and practical capacity was not a limitation on traffic flow through the survey site. Both these sites were therefore eliminated.

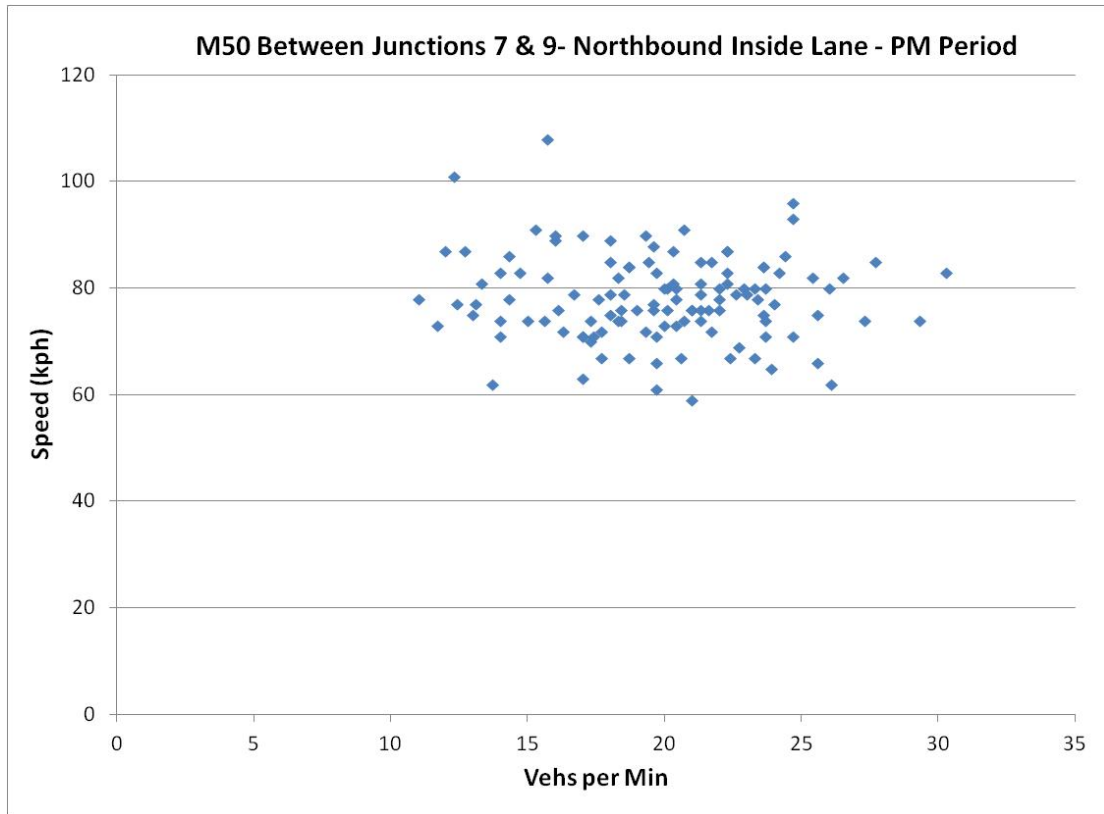


Figure 5.1: Speed Flow Results, M50 Southbound, south of Junction 3

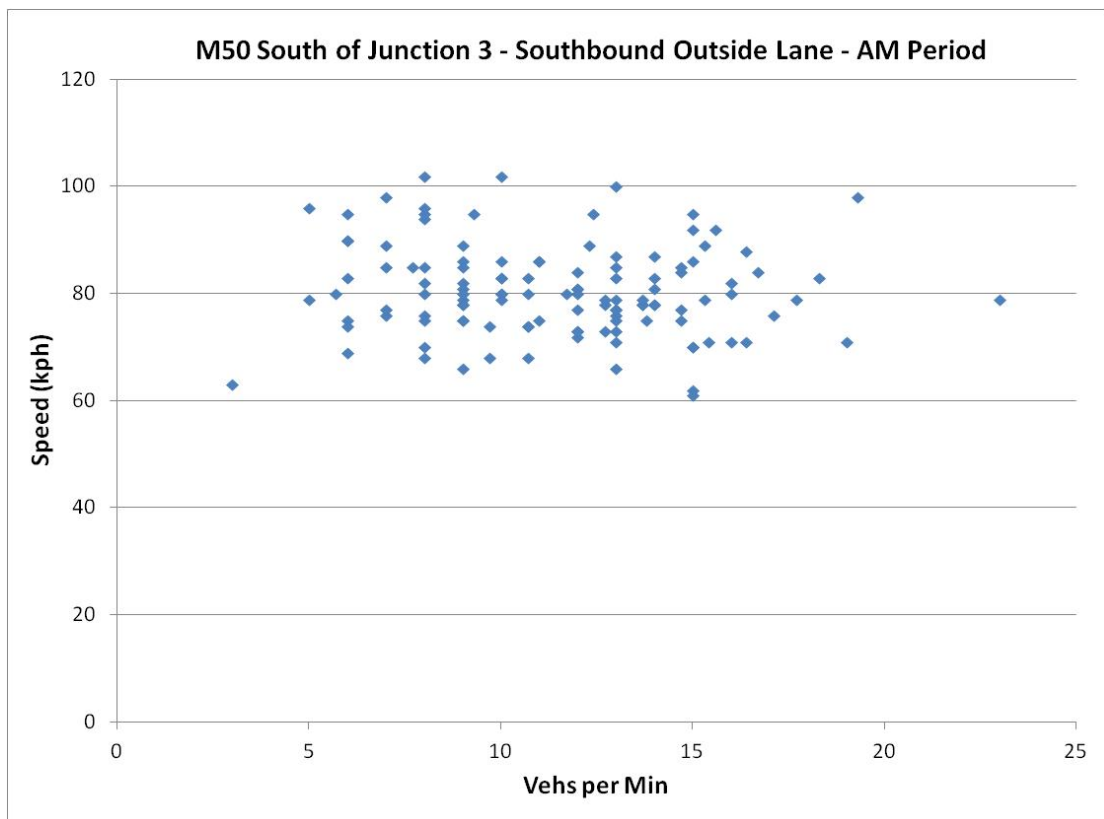


Figure 5.2: Speed Flow Results, M50 Northbound, Junctions 7 to 9

- 5.4. It is evident from the above that a speed boundary of approximately 60kph exists between congested and uncongested conditions on the surveyed sites. This reflects the criteria applied by Lorenz and Elefteriadou, who assumed flow breakdown occurred when average speeds dropped below 60 kph for a period of five minutes or more.
- 5.5. Taking this conclusion, speed flow curves for the remaining sites have been plotted. A selection of plots is presented in Figures 7.3 to 7.6 which show the congested and uncongested periods as red and blue respectively. All vehicular flows are expressed as vehicles per minute.

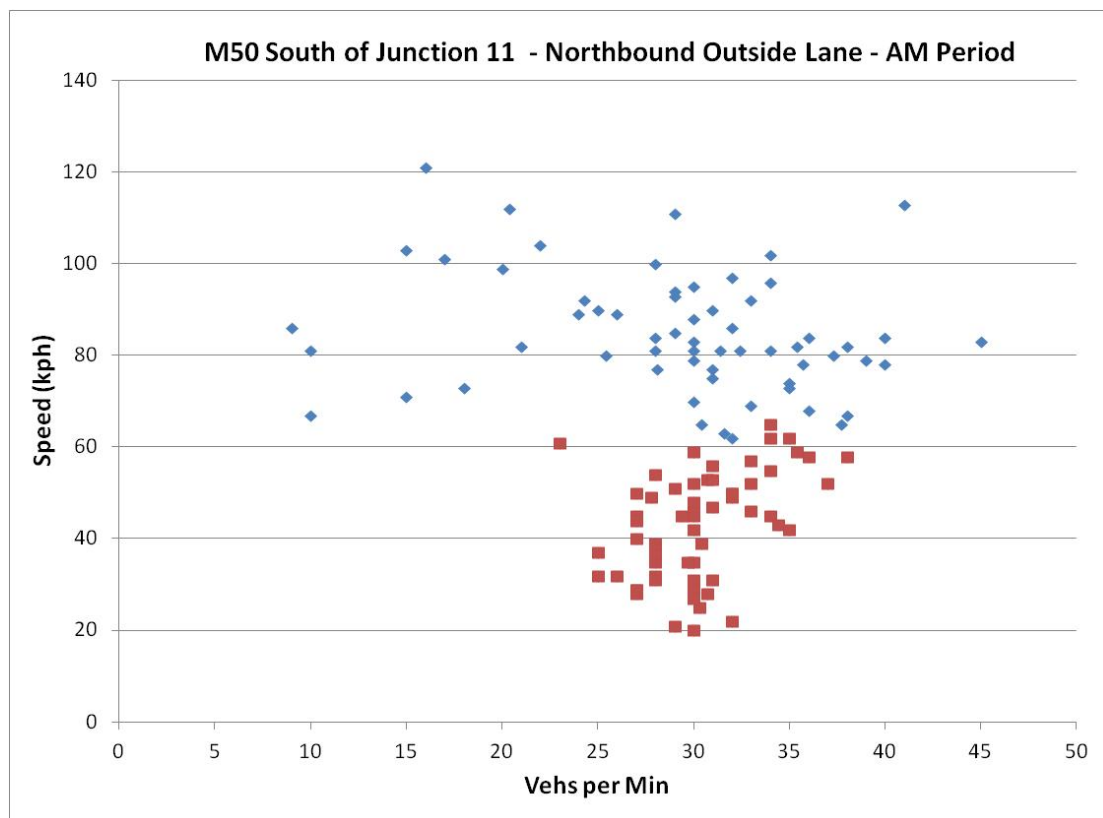


Figure 5.3: Speed Flow Results, M50 Northbound, south of Junction 11

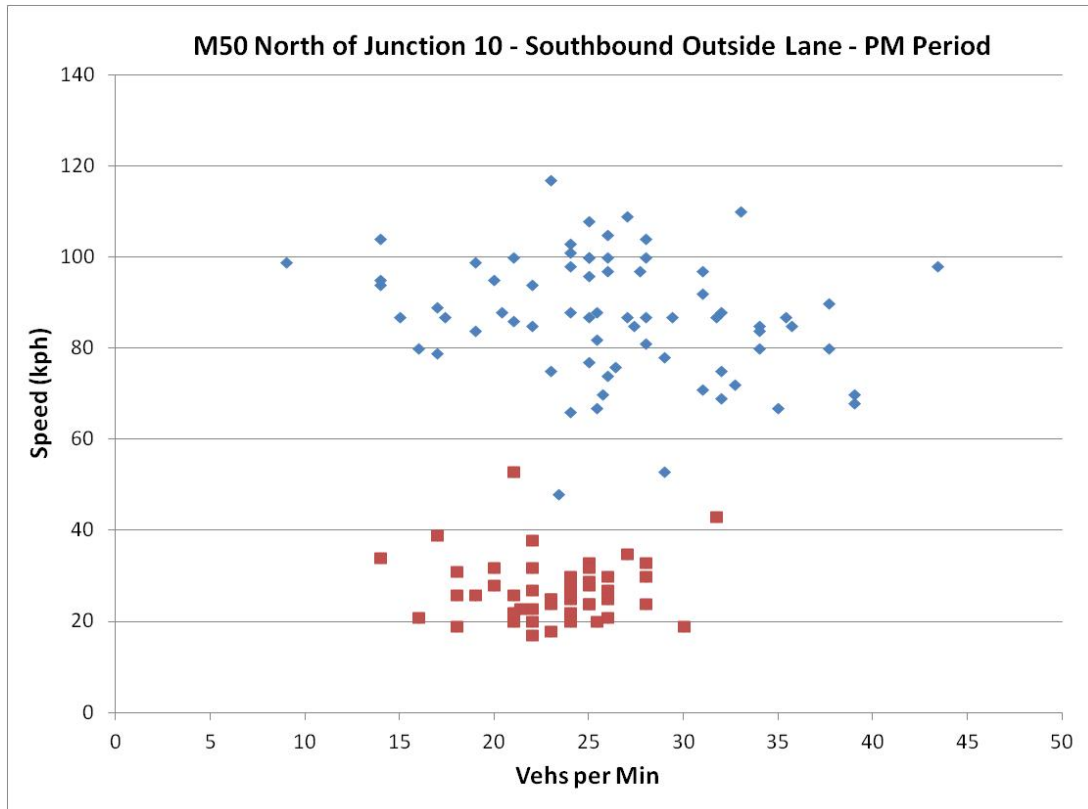


Figure 5.4: Speed Flow Results, M50 Southbound, north of Junction 10

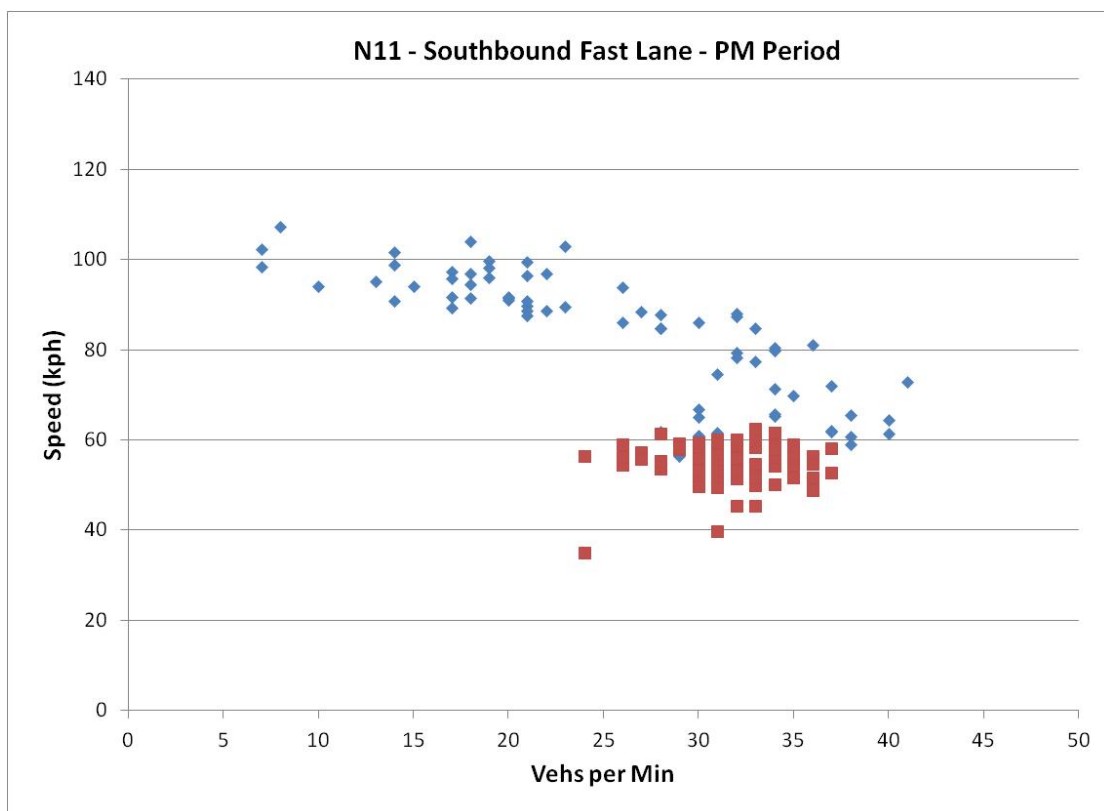


Figure 5.5: Speed Flow Results, N11 Southbound

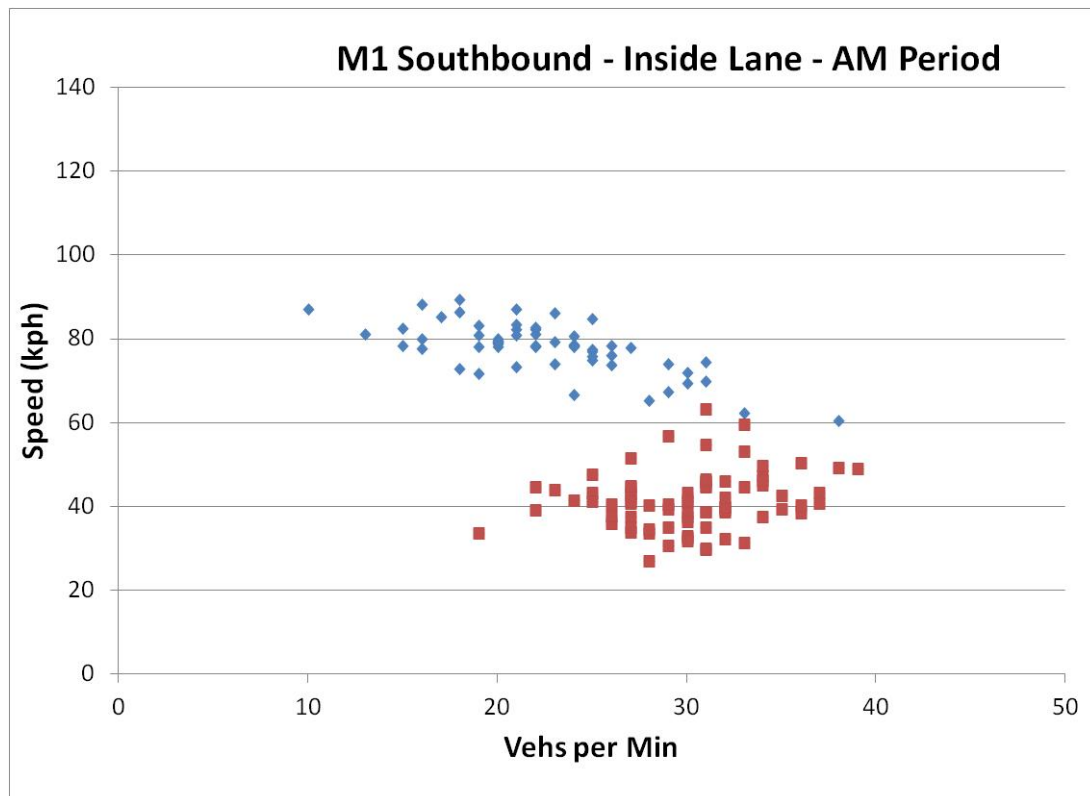


Figure 5.6: Speed Flow Results, M1 Southbound

- 5.6. The results show that adopting the transition of 60kph yields a relatively strong distinction between uncongested and congested traffic flow. For the above examples, the minimum flow at which the uncongested and congested datasets meet is that flow at which the traffic stream became turbulent. This allows the Practical Capacity to be identified.
- 5.7. The full set of speed flow curves across all sites is presented in Appendix A of this Technical Paper. Results are again presented showing congested and uncongested conditions (assuming the 60kph threshold). Table 5.2 below summarises the estimated point of flow breakdown (Practical Capacity) at each location. Where the data does not allow a definitive conclusion, or where flow breakdown does not occur, such data is excluded from the calculation.

Table 5.2: Observed Practical Capacity of Lanes (vehicles/hour)

Location/Lane/Time Period	Lane 1 <i>Inside (Slow) Lane</i>	Lane 2 <i>Middle Lane</i>	Lane 3 <i>Outside (Fast) Lane</i>
M50 South of J11 Northbound AM	1800		2100
M50 South of J11 Southbound AM	1600		1950
M50 South of J11 Southbound PM	1600		1850
M50 South of J5 Northbound PM	1500	1800	1900
M50 North of J10 Southbound AM	1500	1700	1900
M50 North of J10 Southbound PM	1400	1600	1800
M50 South of J10 Southbound AM	1400	1600	1900
M50 North of J17 Southbound PM	1400	1600	1800
M1 Southbound AM	1900		2300
N11 Fassaroe Southbound PM	1700		2100
Mean (veh/hour)	1580	1660	1960
Stdev	175	89	160
Lower 85 Percentile	1405	1571	1800
Heavy Vehicle %	11%	9%	1%
Practical Capacity (pcu/hour)	1715	1862	1824

- 5.8. Examining the full sample of speed flow curves from across all sites, it is clear that the practical capacity of a lane expressed in vehicles/hour is related to the position of the lane within the carriageway. Lane 1 (slow lane) will breakdown into turbulent flow at lower traffic volumes than the fast lane (Lane 2 or Lane 3). It will be demonstrated below that despite the different levels of traffic flow, that breakdown (Practical Capacity) will generally occur at the limit of Level of Service D, and that the maximum capacity of the lane is reached where the traffic stream can be maintained up to Level of Service E.
- 5.9. The combined speed flow data from all sites used for the lane capacity assessment is shown on Figure 5.7 overleaf. The results also show what might be defined as congested and uncongested conditions on the speed flow curve using the 60kph threshold. The use of a 'bounded' speed flow curve assist in describing the variability along the curve at any sample site which results from changes in driver behaviour.

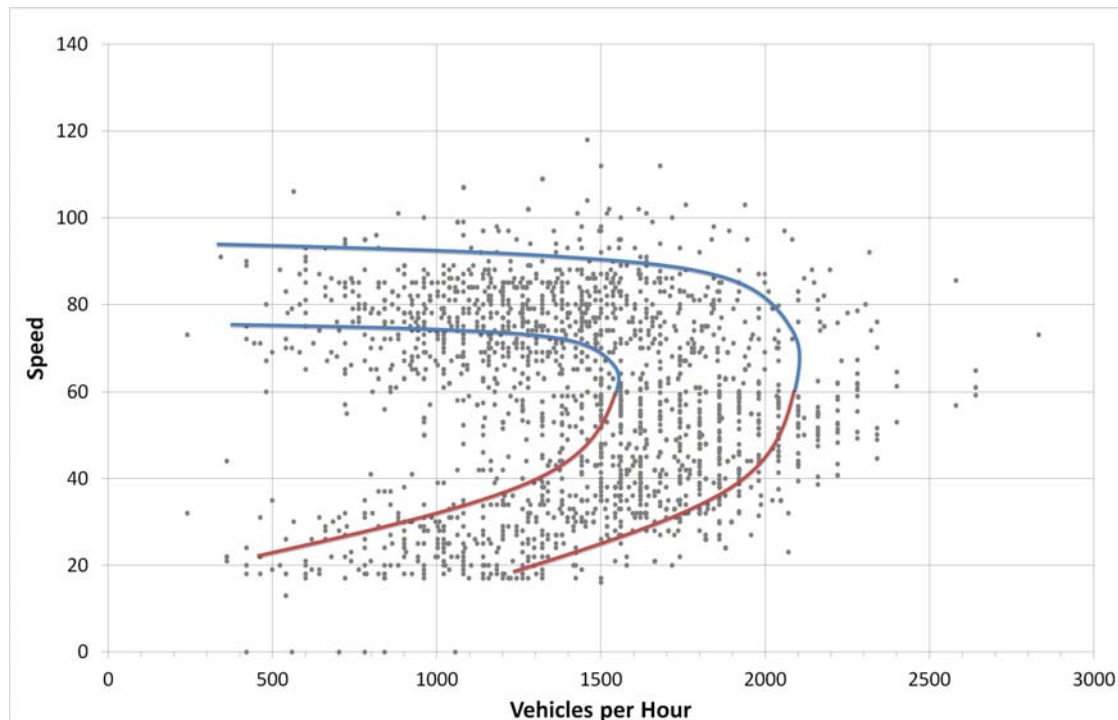


Figure 5.7 – Speed Flow Curve for all sites

- 5.10. The results highlight that the transition into flow breakdown can occur for lane flows as low as 1,500 vehicles per hour. Such instances would occur in slow lanes, where the carrying capacity has been demonstrated to be lower than for other lanes. On the outer band of the speed flow curve, it is evident that lane capacities of 2,100 vehicles per hour are not unreasonable to expect, with traffic flows in excess of 2,500 vehicles per hour recorded at some locations (albeit over very short periods).
- 5.11. Allowing a factor to convert these to Passenger Car Units, it is therefore concluded that flow breakdown becomes a possibility at lane flows of 1,600 vehicles per hour, and properly designed traffic management can increase the Practical Capacity substantially, achieving traffic flows of up to 2,500 Passenger Car Units per hour under extreme conditions.

6. Level of Service

- 6.1. The US Highway Capacity Manual (HCM) specifies a Level of service (LOS) for a road as a quality measure describing operational conditions within a traffic stream. This is generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, and comfort and convenience. Six LOS are defined for various types of routes from A to F, with LOS A representing the best operating conditions and LOS F the worst.
- 6.2. The HCM defines each level of service for motorways (freeways) as follows:

- **LOS A** describes free-flow operations. Free-flow speeds prevail. Vehicles are almost completely unimpeded in their ability to manoeuvre within the traffic

stream. The effects of incidents or point breakdowns are easily absorbed at this level.

- **LOS B** represents reasonably free flow, and free-flow speeds are maintained. The ability to manoeuvre within the traffic stream is only slightly restricted, and the general level of physical and psychological comfort provided to drivers is still high. The effects of minor incidents and point breakdowns are still easily absorbed.
- **LOS C** provides for flow with speeds at or near the Free-flow speeds of the motorway. Freedom to manoeuvre within the traffic stream is noticeably restricted, and lane changes require more care and vigilance on the part of the driver. Minor incidents may still be absorbed, but the local deterioration in service will be substantial. Queues may be expected to form behind any significant blockage.
- **LOS D** is the level at which speeds begin to decline slightly with increasing flows and density begins to increase somewhat more quickly. Freedom to manoeuvre within the traffic stream is more noticeably limited, and the driver experiences reduced physical and psychological comfort levels. Even minor incidents can be expected to create queuing, because the traffic stream has little space to absorb disruptions.
- At its highest density value, **LOS E** describes operation at capacity. Operations at this level are volatile, because there are virtually no usable gaps in the traffic stream. Vehicles are closely spaced leaving little room to manoeuvre within the traffic stream at speeds that still exceed 80 km/h. Any disruption of the traffic stream, such as vehicles entering from a ramp or a vehicle changing lanes, can establish a disruption wave that propagates throughout the upstream traffic flow. At capacity, the traffic stream has no ability to dissipate even the most minor disruption, and any incident can be expected to produce a serious breakdown with extensive queuing. Manoeuvrability within the traffic stream is extremely limited, and the level of physical and psychological comfort afforded the driver is poor.
- **LOS F** describes breakdowns in vehicular flow. Such conditions generally exist within queues forming behind breakdown points.

6.3. It is therefore clear that Traffic Control seeks to protect the traffic conditions that exist under Level of Service E from deteriorating into Level of Service F. From the discussion thus far, it is clear that the transition from LOS E to LOS F is not necessarily related to traffic flow – instead it is a function of the level of turbulence within the traffic stream. Indeed, it is likely that LOS F will support a lower overall traffic volume than LOS E due to the bottleneck resulting from the breakdown.

6.4. This is an important conclusion. It confirms that the LOS definition is not necessarily related to traffic flow. Instead, LOS refers to the ability to manoeuvre within a traffic stream. Indeed, this is reflected within the HCM itself, which specifies the density of traffic as an appropriate way of estimating level of service. The HCM density ranges for motorways (freeways) and the corresponding LOS are outlined below.

LOS	Density Range (pc/km/ln)
A	0-7
B	> 7-11
C	> 11-16
D	> 16-22
E	> 22-28
F	> 28

6.5. It is therefore possible to use the traffic flow relationships of speed, flow and vehicle density to express these Level of Service bands on a speed flow curve. The relevant relationship in this regard is

$$Q = CV$$

Where Q = Vehicle Flow (vehs/hour)
 C = Vehicle Density or Vehicle Concentration (vehs/km)
 V = Vehicle Speed (km/hour)

expressing this in terms of C yields

$$C = \frac{Q}{V}$$

6.6. This can now be transposed onto the Speed Flow curves for the sample sites. For example, LOS A exists where Q/V is 7 or less. LOS B exists where Q/V is between 7 and 11, etc. The resulting plot is outlined below in Figure 6.1.

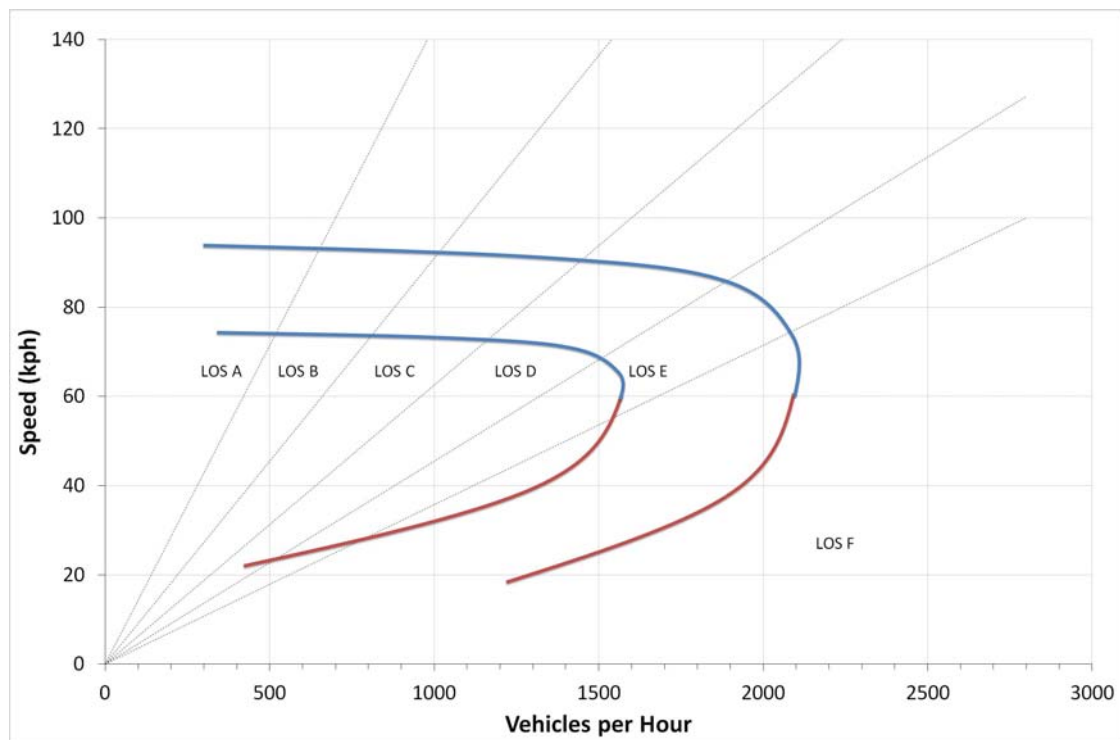


Figure 6.1 – Speed Flow Curves and Level of Service

6.7. A number of findings from Figure 6.1 are worth noting as follows:

- The LOS boundaries correlate very well with the transition into flow breakdown. For the outer boundary of the speed flow curve, the speed deteriorates quickly at the upper limit of LOS D, transitioning into congested conditions through LOS E. A similar pattern is evident for the inner boundary of the speed flow curve;
- All congested conditions occur within LOS F. These conditions are characterised by low flows, but very dense traffic streams;
- Note that a lane flow of 1,500 vehicles per hour will tend to operate at Level of Service D, but under turbulent conditions, the traffic stream can deteriorate quickly to LOS F, but at the same traffic flow; and
- The difference between the inner boundary of the speed flow curve and its outer boundary is a function of the level of turbulence and variability within a stream and also a function of driver behaviour (driving at lower headways or with reduced turbulence within the traffic stream will push the curve outwards).

6.8. The function of Traffic Control is therefore to facilitate a movement towards the outer boundary of the speed flow curve. For the example above, a robust traffic control strategy can increase the traffic flow associated with the upper limit of LOS E from 1,500 veh/hour to 2,100 veh/hour.

7. Conclusions

7.1. The discussion set out in this paper has sought to understand the Practical Capacity of lanes in a traffic stream, using information from the M50 to validate the analysis. A number of pertinent findings are relevant:

- The capacity of a traffic lane can be defined in terms of Practical Capacity (the point at which the flow can start to break down) and Absolute Capacity (the maximum flow attainable under ideal conditions). In this regard, capacity assessment of traffic lanes is similar to techniques used for junction analysis in urban areas;
- Practical Capacity of a lane in a traffic stream is only a limiting factor where there are no downstream effects which disrupt traffic (such as road works or other traffic bottlenecks);
- The Practical Capacity of an unmanaged lane in a traffic stream has been measured to be between 1,700 PCU's per hour to 1,800 PCU's per hour. Higher values result in areas where the level of turbulence in a traffic stream is minimised, and where vehicle headways are low. Although lane flows that are significantly higher than these values have been measured, these are limited observations within a turbulent environment and cannot be maintained for any significant period;
- The Level of Service Concept as set out in the US Highway Capacity manual refers to vehicle concentration, and can occur at a number of combinations of speed and flow in a lane;
- Traffic Management solutions can increase the ability of a road to operate within a defined level of service by reducing turbulence in the traffic stream. This increases the Practical Capacity of a lane, changes the shape of the

speed flow curve by pushing it outwards, and maintains a given Level of Service albeit at a higher lane flow;

- 7.2. The above findings demonstrate the value of traffic management as a tool for increasing Practical Capacity, which should be implemented as lane flows approach the unmanaged Practical Capacity of 1,700 vehicles per hour. In addition, the findings also suggest the requirement for a review of the Level of Service concept as a means of measuring traffic flow/capacity on national roads.

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Appendix A: Individual Speed Flow Curves

