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Modelling Merges at Signalled Junctions

Introduction

One particular highway design feature that does not appear to have been well researched in the UK, is the common design of two ahead lanes merging into a single lane on the exit of a junction. At the time of this publication, neither Transyt or Linsig has a defined software model for modelling this type of merge. Instead, based on the guidance of designing merges on the exits of junctions in the Design Manual for Roads and Bridges, *TD 50/04 Geometric Layout of Signal Controlled Junctions and Signalised Roundabouts, DfT, 2004,* general good practice is to consider a merge of 100 metres or more in length to act as two infinitely long exit lanes, with infinite saturation flow. This model assumes that drivers make their choice of approach lane based solely on delay and that the merge has no impact on approach lane choice. This is significant as approach lane choice defines the flow of each lane and therefore the saturation of that lane. Theoretically, an offside lane to the same destination as a nearside lane, with infinitely long lanes on the exit will have a higher saturation flow than the nearside (*RR67 The Prediction of Saturation Flows for Road Junctions Controlled by Traffic Signals, Webster and Cobbe, TRL, 1966*). In a situation where traffic flow on the approach is at or above available capacity, the flow in the offside lane would be greater than the nearside and the saturation flow of the entire approach (both lanes combined) would be more than double the actual calculated saturation flow of the single lane that both are discharging into. In reality, this can be seen to be mathematically absurd, however it can be explained as the signalled approaches do not constantly receive green and so any resultant sliver queue should theoretically dissipate when the approach is at red. No account of any exit blocking from the merge is taken into account for any of the approaches in the model.

This approach to modelling merges on the exit of junctions has been questioned by some. Based on their experience, the Traffic Signals Team at Cambridgeshire County Council stopped accepting it as reliable some years ago. From anecdotal evidence, some merges appear to function ‘well’ in that they take a substantial amount of traffic and appear to increase capacity beyond that of a single lane. At other locations though, use of the offside lane appears low and does not appear to give any significant benefit. Whilst it can be argued that in capacity terms, it cannot be harming the operation of the junction, the local Highways Authority is still responsible for maintaining the under-used carriageway and detection with the associated costs. Over-estimation of capacity at proposed junctions using this feature may lead to transport planning decisions being made on inaccurate information and inappropriate development being allowed. Furthermore, lightly used offside lanes have been linked in Cambridgeshire and Peterborough to significantly increased offside lane speeds with a corresponding increase in speed differential between merging traffic. In Peterborough at the junction of Bretton Gate and Cavell Close, this has led to the redesign of the junction and the removal of the exit merge on safety grounds, again at the cost of the local Highway Authority. This makes it highly desirable to only build this type of feature where it will be of use and to predict the actual traffic flow and capacity with a reasonable degree of accuracy.

Scope

This paper examines the traffic lane flows on the approaches to junctions in Cambridgeshire and Peterborough, where the lanes merge on the exit. As this feature is not widely used in these areas, this research focuses on a small number of sites from which data is readily available in the form of automatic traffic count data from junction detection. These sites reflect a range of designs of merge, including radii and differences in length of merge. Although only a small sample number of sites is available, a sufficient quantity of data shall be collected from each to make a quantitative assessment of lane flows at each site.

Beyond patterns in lane flow, this paper explores if and how the results could be incorporated into a Linsig model.

This paper will not consider the impact of variations in the design of merges, other than to note deviations from good practice where the wider application of the results could be called into question. Neither will it consider micro-simulation modelling of merges.

Hypothesis

Driver lane choice on the approach to a junction can be influenced by the lanes merging on the exit of the junction. Some drivers will naturally remain cautious and will always take the nearside lane, while some will normally take the offside lane. Others will make a decision based on their perception of risk, delay and their experience.

If the above statement is true, then the statements below may follow:

- The majority of drivers will err towards caution for any given situation and so the traffic flow in the nearside lane will normally be greater than the offside.
- The effect of risk, experience and delay on driver choice can be modelled statistically and therefore be represented in a traffic signal macro-simulation package such as Linsig.
- Traffic flow in each lane is directly related to the total flow and can be expressed as a linear equation. This can be modelled in Linsig using the existing give-way model with appropriate values for Y-intercept and co-efficient.

Methodology

Three sites have been identified across Cambridgeshire and Peterborough, at which there are a total of four approaches with two lanes merging on the exit and traffic flows for each lane are available. Vehicles in each lane have been counted at two of the sites (three approaches) from loop detection at the stop lines by way of a remote monitoring system. At the third site, a classified turning count survey was being carried out from which the data has been used. Because classified count data was not available from the remotely monitored sites, only the vehicle counts from the classified survey have been included in the initial data analysis. While this could add a degree of error, an assumption has been made that the traffic composition of the three sites is largely similar (predominantly cars and light traffic, <10% HGV or bus) and so any correlation should remain broadly true for classified results. Some adjustment needs to be made though as it is unlikely that any HGV or bus traffic would use the offside lane and so the classified turning counts, converted to passenger car units (PCU) for the nearside lane may be higher than the offside. Assuming HGV and Bus traffic equals ten percent of all traffic in the nearside lane; the likely flow is approximately 1.2 times the vehicle count for the lane. This has been tested by comparing the vehicle and classified counts at Site 3 and is broadly accurate.

To compare the lane flows against the total flow, count data is collated at 15 minute intervals for 48 hours at sites 1 and 2. At site 3, as the survey is a manual survey, no overnight data is available, so 24 hours of data over 2 days (7.00 - 19.00) has been used. The lane flows for each site are compared against each other and against the total flow on the approach with the results plotted graphically. A trend line is fitted against the data and the equation of the best fitting trend line and the coefficient of determination (R2) is calculated. This gives an indication of the quality of fit of the trend line to the data and the likelihood of the trend line reflecting future results for the same conditions. All of the data is then collated and a trend line, equation and coefficient of determination calculated to give a standardised result that could be used to create a model for traffic flow at any junction with a merge on the exit.

The linear equation for the standardised trend line, modified to reflect PCU, is imported into a simple Linsig model with two lanes giving way to each other after a signalled ‘junction’. Benchmark flows of 100 pcu and increasing increments are applied to the model and Linsig is allowed to automatically allocate traffic to routes based on delay and the give way model. Although the give way model in Linsig can easily model any linear equation with positive Y-intercept, data entry of the coefficient is restricted to negative values only (the negative value is applied after data entry), as typical right and left turn give way models show decreasing flow with increasing opposing flow, thus negative coefficient. JCT Consultancy have assisted in this research by providing an adapted version of Linsig 3.1 for testing this Hypothesis. In this version, the restriction on data entry has been lifted, allowing the model to be used.

The Simple Model has two infinitely long lanes on a single approach. These are configured as signal controlled, with the lanes configured as per the approach lanes at Site 3 and saturation flows calculated to RR67 by Linsig. They exit into two lanes, initially configured as infinitely long but with equal saturation flow to the approach. These two lanes then exit into a single infinitely long lane with infinite saturation flow. A second arm and lane, with notional saturation flow, uncontrolled exits into the same final lane. Both the nearside and offside exit lanes are configured as giving way, opposed by the second arm. Give way characteristics are as defined in the results from Data Analysis, below, for each lane. Two entry zones are created, one for each approach arm, and a single exit zone. The total benchmarked flow is allocated to both entry zones, all exiting to the same exit zone and the model allowed to allocate traffic to routes.

The above model is then used in a full Linsig model of Site 3, based on the classified turning count data, with correction to the give-way equation and comparing the modelled lane flows to observed lane flows to ensure that the principles and technique remain true in a wider model.

Sites

Site 1 - Hauxton Road / Addenbrookes Road, Cambridge

The junction is a large, four arm junction on the outskirts of Cambridge and is the first junction after Junction 11 of the M11 when travelling into the City. Speed limit is 40mph and the road is wide with multiple lane approaches on all arms. Data from two approaches on a single arm have been collected. The arm is the inbound Hauxton Road approach, five lanes, with a left turn lane; two ahead lanes, merging on exit and two right turn lanes, merging on exit. Both merges are DMRB designed (100m+) and the right turn has an approximate inside radius of 50m. All approaches (left turn, ahead and right turn) are separately signalled. Approaches flare from single lanes for each approach approximately 100m in advance of the junction.

Site 2 - Bretton Gate / Cavell Close, Peterborough

The junction is a T-junction with separately signalled right turn on one main road approach and two ahead lanes on the other. The nearside of the two lanes also has left turning traffic into the side road for the Peterborough City Hospital. Lane flow data includes left turning traffic. The merge on the exit is below 100m but is typical of many merges at 80m. The two ahead lanes flare from a single lane 100m from the stop line. Since the data was collected the nearside lane has been restricted to left turning traffic only and the merge removed due to the safety concerns highlighted in the introduction.

Site 3 - Churchill Road / Weasenham Lane / Ramnoth Road, Wisbech

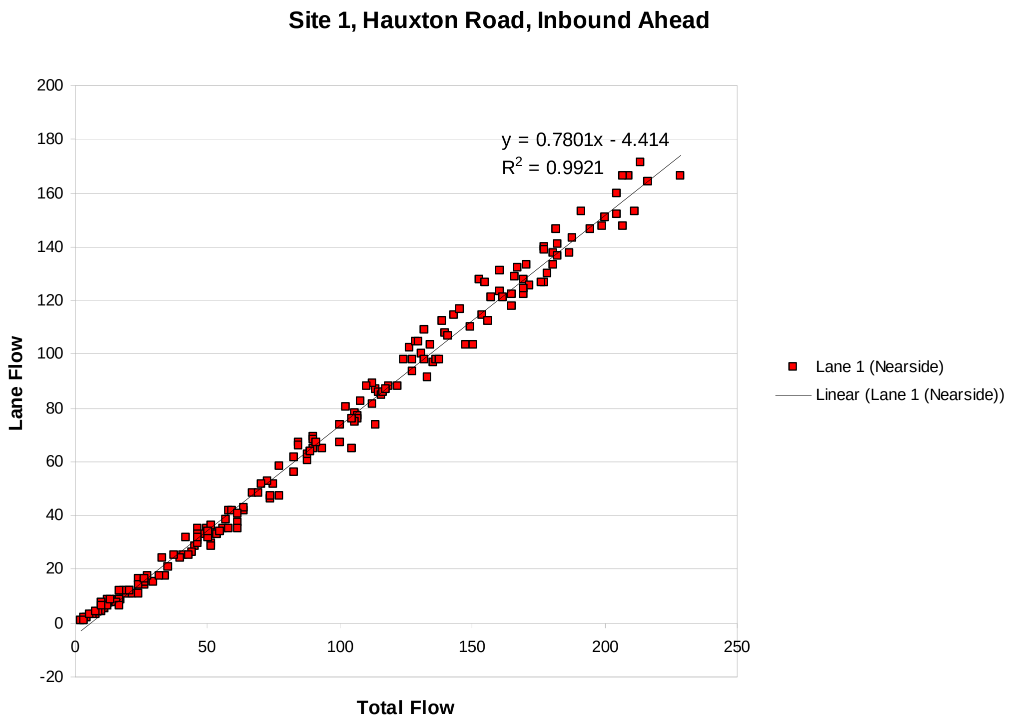
The junction is a four arm junction with the two minor arms staggered by approximately 40m. The junction is at the end of a 40mph dual carriageway into the town centre. Outbound on Churchill Road, there are two lanes of the dual carriageway which merge into one on the exit (ahead). A right turn lane is flared off 60m in advance of the outbound stop line and left turning traffic into Ramnoth Road shares the nearside lane. The merge is technically below DMRB guidance at 60m, however, due to the distance between staggered side roads, drivers effectively begin merging much earlier through the junction, allowing 100m. Towards the end of the merge there is also a give way slip onto the road from the uncontrolled left turn out of Ramnoth Road, although it has very low flow.

Results of Data Analysis

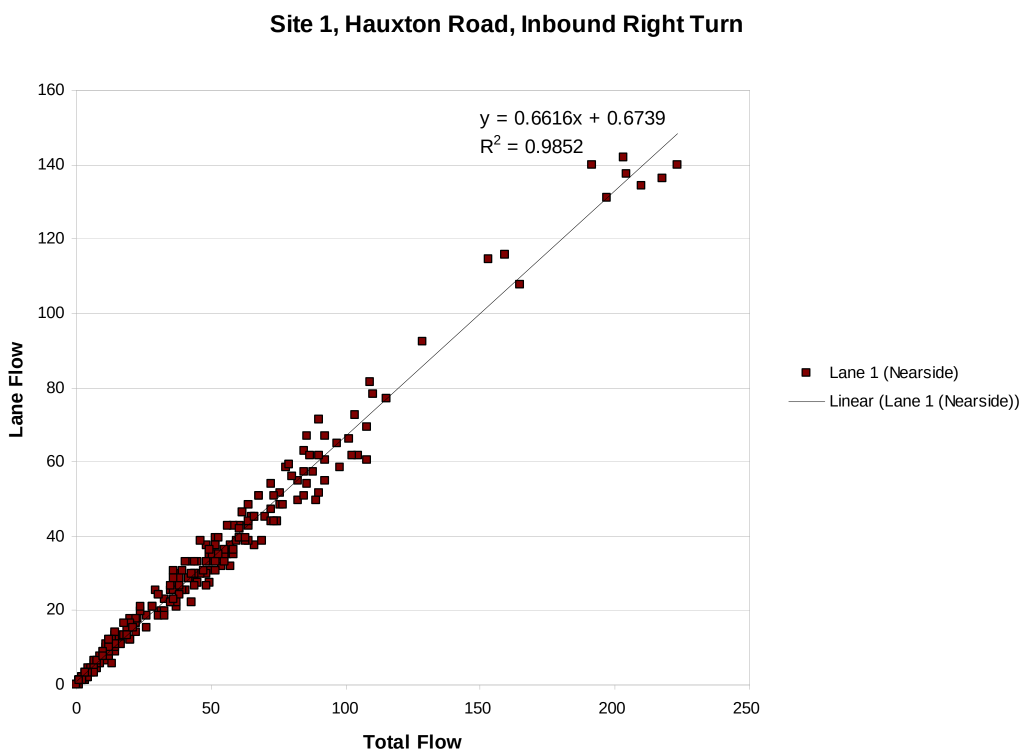
All four of the approaches analysed show a clear linear relationship between the flow in each lane to the total flow, as predicted by the Hypothesis. To improve on the accuracy of the linear equation to be used in modelling, converting it to PCU, the nearside lane flows and total flows have been modified to take into account an estimated 10% HGV / Bus flow in the nearside lane. Nearside lane flows have been modified by multiplying them by 1.1 times the original.

Graphical representation of the data and trend lines for the four approaches are shown in Graphs 1 - 4 below. A graph of the aggregated data is shown in Graph 5.

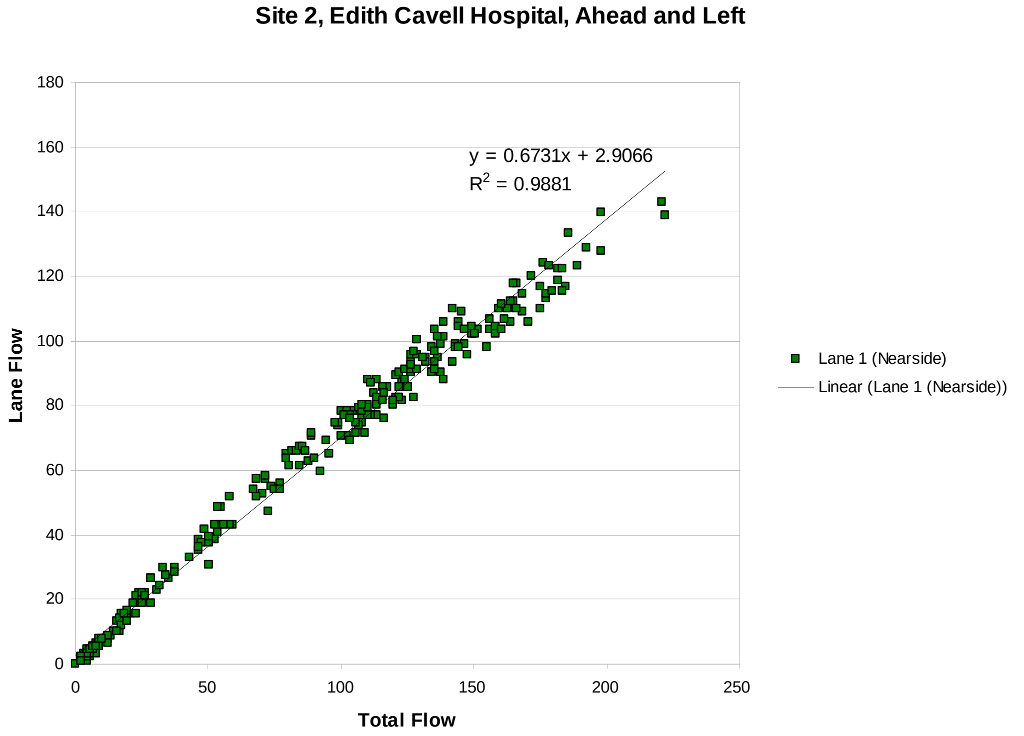
Graph 1 - Site 1, Hauxton Road / Addenbrookes Road, Approach 1, Nearside Lane Flow against Total Approach Flow.



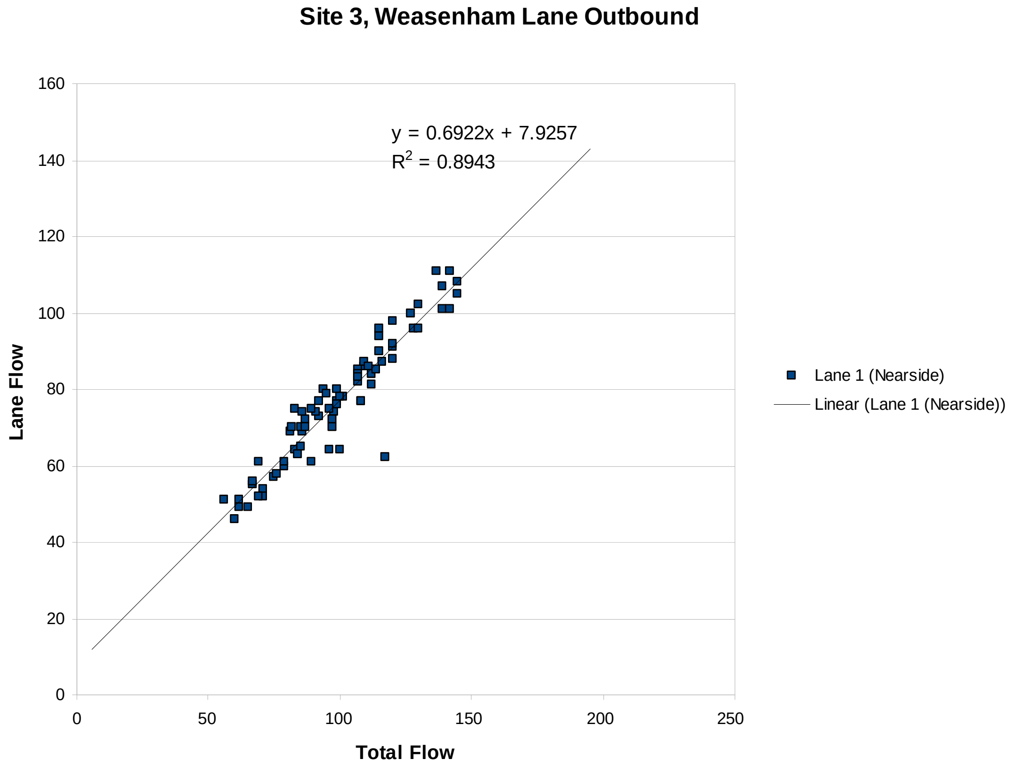
Graph 2 - Site 1, Hauxton Road / Addenbrookes Road, Approach 2, Nearside Lane Flow against Total Approach Flow.



Graph 3 - Site 2, Bretton Gate / Cavell Close, Nearside Lane Flow against Total Approach Flow.

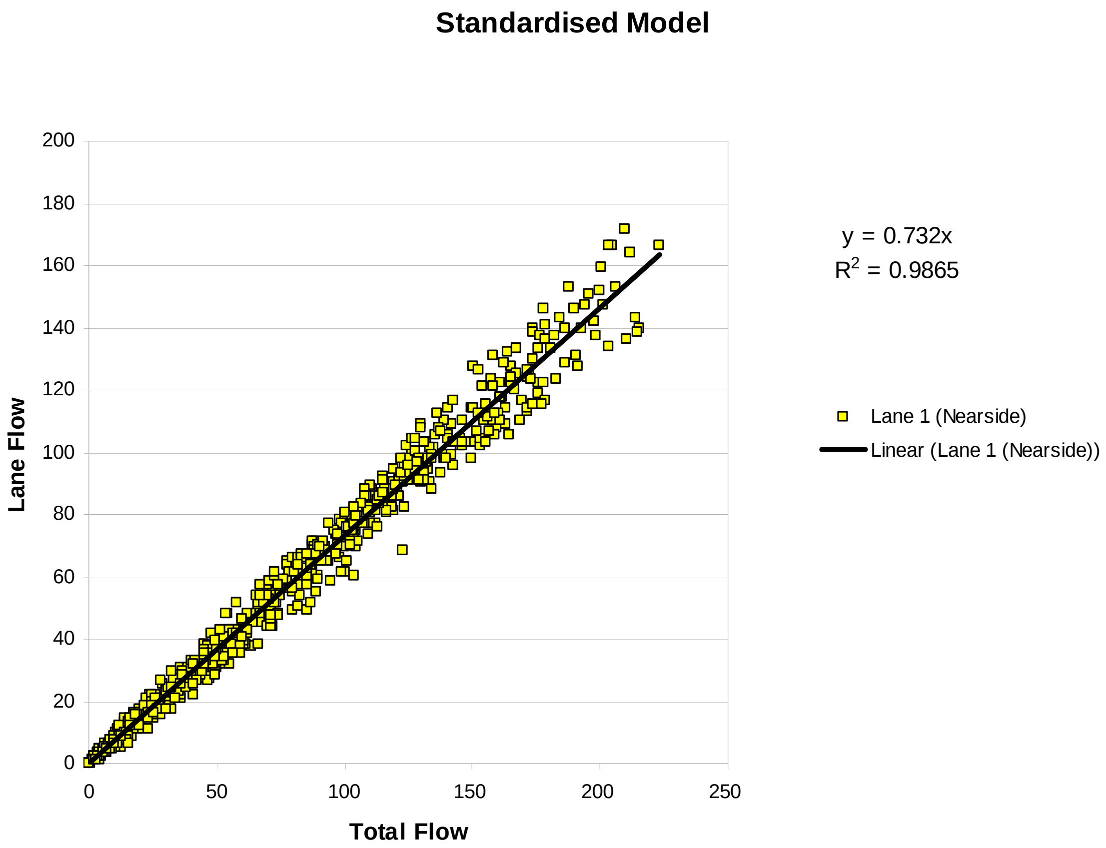


Graph 4 - Site 3, Churchill Road / Weasenham Lane, Nearside Lane Flow against Total Approach Flow.



The correlation between the offside lane flow and total flow is not shown for simplicity. As the only two factors of Total Flow are the nearside and offside lane flows, the relationship between offside lane flow and total flow is simply 1 minus the equation for the nearside lane. It is not of as much use however, as due to the lower flows, the result cannot be determined to be as accurate.

Graph 5 - Aggregated Flows, Nearside Lane Flow against Total Approach Flow (Standardised)



It is clear from these results that not only is there a direct relationship between the nearside lane flow and total flow but that there is an unequal balance of flow between nearside and offside lanes, corresponding to the total flow of traffic. Simply put, as traffic flow increases, there will always be a greater number of vehicles using the nearside lane to the offside, where the lanes merge on exit. As the Y intercept is close to zero, traffic distribution can be expressed as a percentage of total traffic, (73.4% of PCU using nearside lane) or even as a direct ratio of approximately 3:1; this is shown in the standardised model in Graph 5 above, where the Y intercept has been omitted. Furthermore, the coefficient of determination is high enough for the trend line describing the aggregated data that it can reliably be used as a model to predict lane usage at these junctions in the future. Although there are only a limited number of sample junctions, considering the diversity of the junctions sampled and the closeness of the fit to the trend, it suggests that the results are likely to be accurate for other sites, although a larger sample size would be needed to prove this conclusively.

Site, Approach	Coefficient	Y-Intercept	Coefficient of Determination
Site 1, Ahead	0.78	-4.4	0.99
Site 1, Right Turn	0.66	0.67	0.99
Site 2	0.67	2.91	0.99
Site 3	0.69	7.93	0.89
Aggregated	0.73	-0.22	0.99
Standardised	0.73	0	0.99

Table 1 – Linear Regression for Corrected Data

The results do clearly demonstrate however that the standard model of assuming that the merge acts as two infinitely long lanes is likely to be inaccurate at many, if not most sites to the point of being misleading, regardless of the length of the merge.

Results of Linsig Analysis - Simple Model

Results of the Simple Model show that Linsig can be used to distribute traffic through the model in accordance with the demonstrated trend. Although the traffic flows are only notional, the results of the simple model show that the desired percentage split of traffic across lanes can be achieved using the give way model to influence the delay based distribution of traffic. This technique alone could therefore be used on it’s own to provide a reasonably accurate model of lane flows which could be used to manually allocate traffic in other models for example.

A second version of the Simple Model was also tested, opposing each lane with the other. This did not yield the desired percentage distribution of traffic with the appropriate values entered for the give way model. It is not clear at this stage why this was not successful and a deeper analysis of the Linsig give Way model is required to understand the reason.

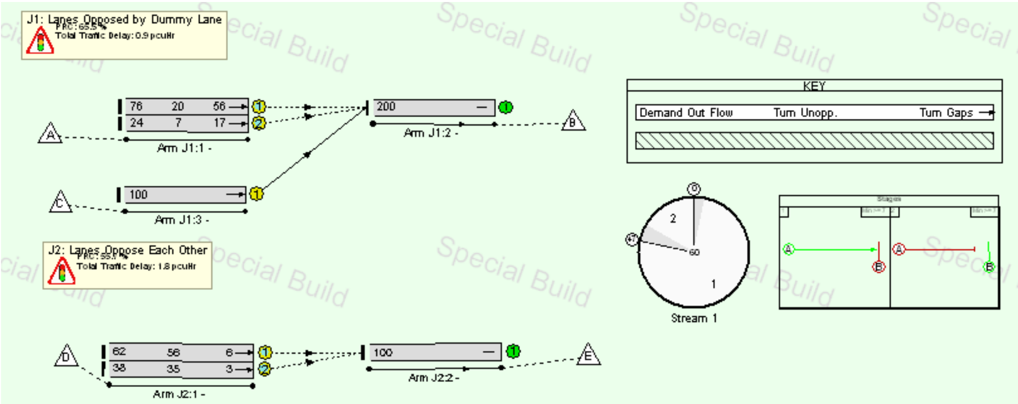


Diagram 1 - Simple Model

Results of Linsig Analysis - Complex Model

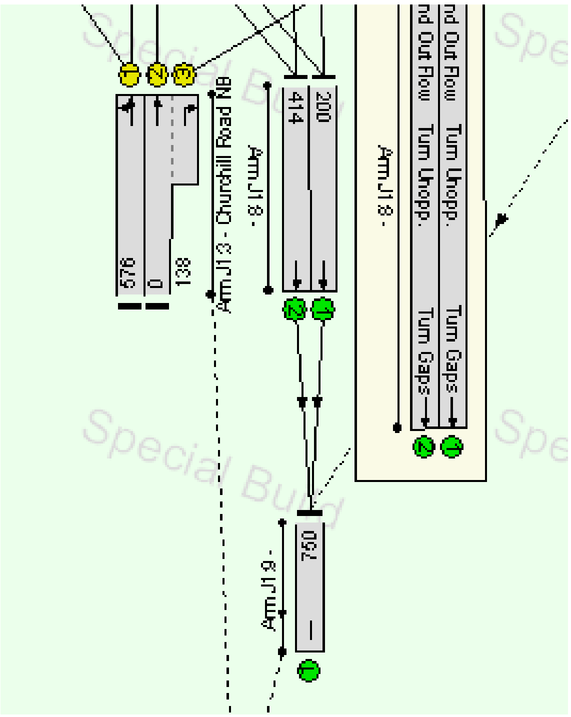
A full Linsig model was created for the Weasenham Lane junction, with the technique described and demonstrated by the Simple Model applied to the outbound lanes at the point at which they merge. Traffic flows were entered for five hours from the recorded 12 hour classified turning count, using a single zone for each arm. All possible routes were enabled and the traffic flows were automatically distributed between routes by Linsig, using delay based allocation with preferences set to default values.

ORIGIN	DESTINATION			
	Churchill Road	Ramnoth Road	Elm High Road	Weasenham Lane
HOUR 1	A	B	C	D
A		24	338	209
B	33		144	153
C	380	137		289
D	229	67	180	
HOUR 2	A	B	C	D
A		13	450	164
B	15		107	54
C	459	65		202
D	185	65	225	
HOUR 3	A	B	C	D
A		21	429	148
B	6		117	76
C	419	83		204
D	169	85	216	
HOUR 4	A	B	C	D

A		15	471	160
B	23		168	87
C	452	120		180
D	250	100	221	
HOUR 5	A	B	C	D
A		34	435	159
B	20		136	65
C	413	138		163
D	228	134	179	

Table 2 - Traffic Flow Matrix

Table 2, above, shows the classified turning count data for 5 hours through the day of the turning count at the Churchill Road / Weasenham Lane junction (Site 3).



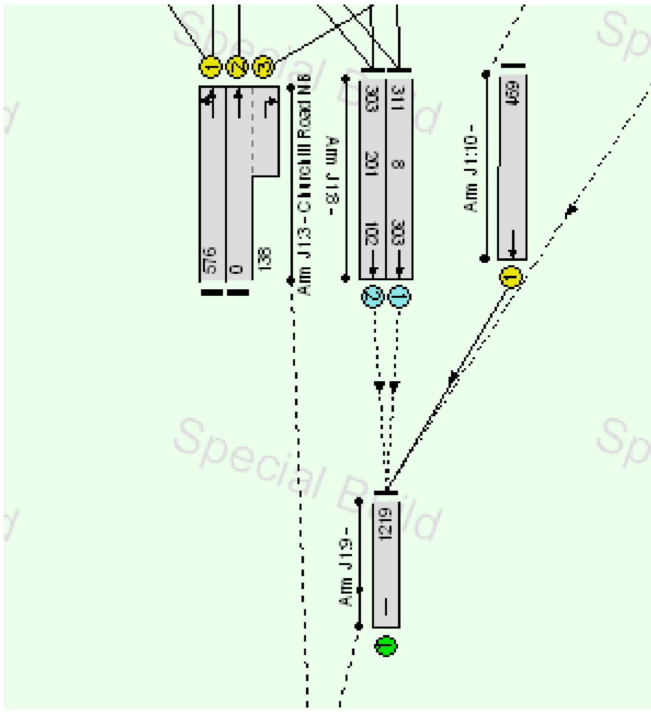


Diagram 2 - Base Model

Diagram 3 - Test Model

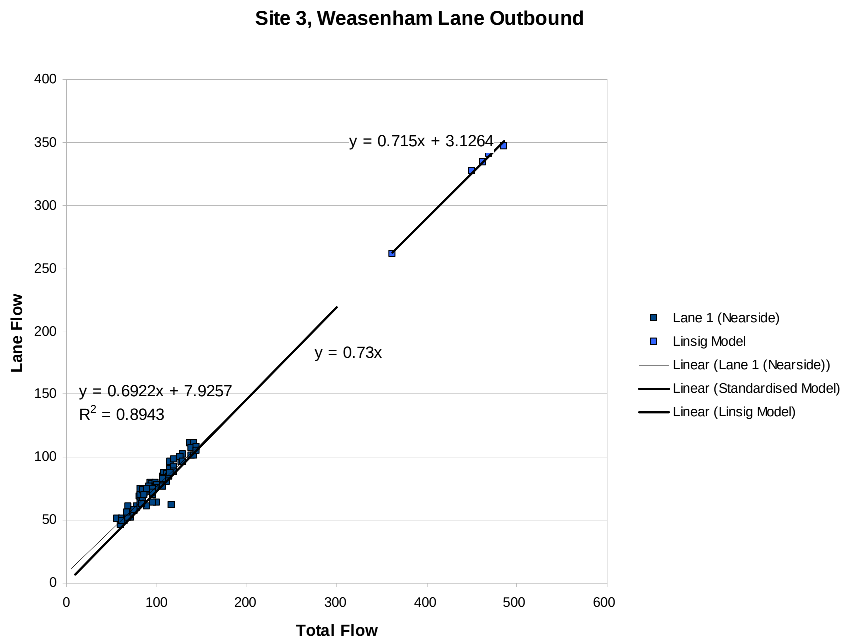
Diagram 2 and 3 show how the Southbound exit from Churchill Road is configured with the Base Model reflecting the practice of configuring both exit lanes as infinitely long. In the Test Model by contrast, both exit lanes are opposed by a ‘Dummy’ Lane. The nearside lane has a coefficient of (+)73 and Y-Intercept of 1, as Linsig requires an integer above 0. The offside lane has a coefficient of (+)27 and Y-Intercept of 1. Flow in the offside exit lane still remains higher than the nearside as a result of the double-right turn exit from Weasenham Lane, which directs traffic into the nearside. The effect of traffic distribution on the approach though is in keeping with the prediction of the simple model and a comparison of lane flows are shown in Table 3 below.

	Lane 1 (Churchill Road) Flow			Comparison Against Measured Flow	
	Base Model Forecast	Test Model Forecast	Actual	Base v Actual	Test v Actual
Hour 1	181	261	296	61%	88%
Hour 2	233	334	397	59%	84%
Hour 3	226	327	367	62%	89%
Hour 4	244	347	379	64%	92%
Hour 5	234	341	343	68%	99%

Table 3 - Lane Flow Comparison

It is clear from the comparison between the base and test models, that the Test Model is significantly more accurate than the Base Model. Although the test results only predict an average 90% of the actual flow in the nearside lane, this is in keeping with the original analysis of lane flows, which suggested a similar difference between this site and the standardised trend. This can be seen in Graph 6, where the actual results, standardised model and Linsig results for Weasenham Lane are overlaid for comparison. The Linsig model results are higher as they are hour flows. Actual Results are shown as 15 minute counts.

Graph 6 - Site 3, Weasenham Lane Results and Standardised Model



Although this value is below ideal, it is within an acceptable margin of error for traffic modelling. This demonstrates that the simple model can be expanded and incorporated into a full Linsig model to provide a reasonable estimate of lane flows and therefore capacity, although further work is required to prove that accuracy is acceptable across a wider range of sites. This may be achievable through manipulation of the existing Linsig give way model factors.

Limitations

Although the data gathered so far appears statistically significant and therefore presents a good model for those sites included in the study, there are a number of limiting factors:

- Small junction sample size
- Relatively close geographic proximity
- All sample sites were ‘suburban’ rather than urban.

The small sample size and relatively close proximity of all the sites, does lead to the possibility that the effect demonstrated is regional. While it is likely that there is a linear relationship between traffic flow in each lane at sites across the country, it is possible that the co-efficient of the relationship may be different. This may also be true of urban sites, where increased traffic flows, congestion and differences in driver behaviour may lead to an increased use of offside lanes and therefore a lower coefficient.

Although the Linsig model appears reasonably accurate for the model of Site 3, further junction modelling is required to demonstrate that the range of margin of error for the model is acceptable to apply across other sites without detailed validation.

Conclusions

The initial Hypothesis is correct in the statements set out above, at least in Cambridgeshire and Peterborough. The majority of drivers at the sample sites did favour the nearside lane over the offside. Furthermore, traffic flow in each lane does have a linear relationship with the total flow, to some extent regardless of physical design features. This can be modelled statistically and can be modelled in Linsig, either by adaption of the give way model to influence traffic flow distribution, or potentially by the introduction of a ‘throttle’ on merging lanes to influence the route allocation, where there is a choice.

The adapted Linsig Test model used did not provide the level of accuracy that the strength of the relationship suggests could be achieved. While Site 3 did have a slight variation in the trend, it does not account for the 10% average difference. This shows that there are still other factors within the current Linsig model that are not optimal and are having an undesired effect. Exploration of the available variables could reduce this error margin further.

The relationship between each lane and the total flow is not equal and traffic flow favours the nearside lane. This directly contradicts the established methodology for modelling merges in macro-simulation packages. While having an offside lane merging on the exit does increase capacity, it does not provide the benefit of a second lane, and the perceived problem of differential speeds between nearside and offside lanes may be more acute and occur at higher total flows than previously thought. At some locations this may mean that a flared lane and merge is not of sufficient value for the increased risk; at others it may mean that a proposed junction that previously modelled as having acceptable capacity no longer performs acceptably.

Further Areas for Research

The testing undertaken so far, although demonstrating the relationship and that it can be modelled, does not identify any factors that could influence traffic flows, other than the common factor between all sites, namely the merge. Further detailed research of a greater number of sites is required to conclusively prove that the observed statistical model is accurate across other regions. Analysis of other variables such as length of approach lane or merge is also needed to establish the parameters within which the model applies and how to best optimise the design of merges at junctions for capacity and safety.

Comparison of the above model with micro-simulation packages could allow iterative development of further research and examination of variables without the need for as many real sample sites.

References

Many thanks for assistance given by JCT Consultancy Limited, for the bespoke version of Linsig they created to allow software modelling to be undertaken. Thanks also to Peterborough City Council for providing count data.

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