An investigation into the safety benefits of Flag Lighting at New Zealand State Highway intersections

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Abstract

This project aims to improve our understanding of how flag lighting (i.e. one to three lights at rural intersections) influences the number of night-time crashes. It is known that road lighting has significant safety benefits. Before and after studies both here and overseas indicate reductions in crashes of around 30% where route lighting has been improved. There is persuasive evidence from overseas that flag lighting is a legitimate and useful road safety tool but to date local information has been lacking.

The project used a database of state highway intersection crashes and intersection characteristics produced by the use of the CAS system of Police reported crashes matched to a number of databases containing road infrastructure and vehicle flow information. Statistical analyses were then carried out which suggested that the impact of flag lighting on crashes is only a little behind that of full lighting with both resulting in a reduction of the ratio of night crashes to day crashes of around 30%. Two flag lights gave a higher crash reduction than a single light at all types of intersection but particularly at crossroads. Adding further lights in excess of 2 rarely produced further crash reductions.

Rear end and hit object crashes benefited most from flag lighting. These crashes showed a 45% reduction in the night to day crash ratio. The presence of these types of crash in the crash record may be a pointer to the sites that would benefit most from flag lighting.

The flag lighting variables best indicating how flag lighting performance may be optimised were the number of luminaires per intersection and the total lumen package applied at flag lit intersections. The safety impact of the size of the total lumen package is related to the number of lights and their power.

1 Introduction

This project aims to improve our understanding of how flag lighting (i.e. one to three lights at rural intersections) influences the number of night-time crashes by providing local information from the state highway network.

It is known that road lighting has significant safety benefits. Before and after studies both here and overseas indicate reductions in crashes of around 30% where route lighting has been improved. There is also persuasive evidence from overseas that flag lighting is a legitimate and useful road safety tool. For example, Bruneau and Morin (2005) studied 376 rural and near-urban intersections, with both continuous standard lighting and nonstandard lighting, using a single light mounted on a utility pole. The non-standard lighting corresponds to our flag lighting. Both three- and four-approach intersections were included. The results showed reductions of 29 percent in the night-time crash rate for non-standard lighting and 39% reduction for standard lighting. Another example is Kim et al. (2006) who took a different approach using crash prediction models with lighting included as a variable. The data used 837 motor vehicle crashes collected at 165 two-lane rural intersections in the US state of Georgia. The total crash model revealed a positive relationship between lighting on the major road and safety. Significant relationships were also found for side-swipe crashes, pedestrian crashes and angle crashes with rear-end crashes also close to significance at the 0.05 level.

Hallmark et al (2008) of Iowa investigated the impact of lighting on driver safety at unsignalised rural intersections in Iowa. The research considered only whether lighting was either present or absent, not its intensity or quality. Crashes were tabulated based on this binary measurement and ratios were created. Results showed that the ratios of night-to-day and total night crashes were lower at lighted intersections compared to unlighted intersections. Again all the intersections qualified as flag lit.

Examples of other publications providing broadly similar results are Edwards (2015), Smadi et al (2011), Isebrands et al (2010) and Preston and Schoenecker (1999).

2 Method

2.1 Metrics used to indicate the impact of lighting

This work used both the ratio of night crashes to all crashes and the ratio of night crashes to day crashes as metrics to indicate the impact of lighting. This work considered only sites where there was at least one crash in the study period. This was because sites with no crashes over the study period contribute no useful information on the relative risk of day versus night crashes.

Day time crashes will generally be unaffected by the presence of street lighting and so provide a measure of crash frequency largely independent of the street lighting. By examining the number of night crashes at each site and expressing that as ratio to the number of day crashes a relative measure of night time safety performance is established. This method was employed in recent urban and extra-urban studies of route lighting (Jackett and Frith, 2012), (Frith and Jackett, 2015), by Scott (1980) and a number of others.

The ratio of night time crashes to all crashes may be used similarly. This ration is particularly useful in generalised linear modelling (GLM) where the ratios are used on an individual site basis. This is because sites where crashes occur during the day, but the number of night crashes is zero are not excluded because a zero in the denominator makes the ratio undefined. Thus, by using total crashes as the denominator, any site which has at least one crash, be it day or night, may be used in the model.

In this paper both GLM analyses and contingency table are uses to assess how flag lighting impacts on the safety of intersections. The GLM analyses performed use all crashes (including noninjury crashes) as the denominator of the ratio and the contingency table analyses use day crashes (including noninjury crashes) as the denominator.

2.2 Sample selection

The project used a database of state highway intersection crashes and intersection characteristics produced by the use of the CAS system of Police reported crashes matched to a number of databases containing road infrastructure and vehicle flow information.

The project used a database of state highway intersection crashes and intersection characteristics produced by the use of the CAS system of Police reported crashes matched to a number of databases containing road infrastructure and vehicle flow information. The databases used were from SLIM, KiwiRAP, MobileRoad, and CAS and the common linkage between them was the State Highway Route Position (RP). The final database 0f 1622 intersections with at least one crash within the study period is shown in Table 1.

Item	Unlit sites	Flag lit sites	Fully lit sites	All sites
No of sites with at least 1 crash	847	470	305	1,622
Total number of crashes	1,283	993	1092	3,368
Total crashes at night	408	246	263	917
% of crashes at night	32%	25%	24%	27%

Table 1: Distribution of the sites between the different light categories

The crashes included in the study were those within an RP range of plus or minus 50 metres which served the dual purpose of including crashes on the approach and departure from intersections and increased the chances of capturing the intersection crashes where there was a small error in the RP.

The +-50 metres range was selected after a brief sensitivity analysis. Higher values would increase the sample size but also increase the data noise as it became possible to include crashes from adjacent intersections. Statistical significance for a range of changes was found to be little affected within the range 30 to 80 metres and consequently value of 50 metres was chosen as a reasonable compromise.

The major variables available in the final database were:

- Lighting (using KiwiRAP definitions of unlit, flag lit (<=3 lights), fully lit (>3 lights)
- Lighting (from SLIM data the number of lights at the intersection – limited availability)
- Lighting (google street view observations on the number of lights at the intersection)
- Lumen package (sum of lamp lumens at the intersection- limited availability)
- SH Traffic volume (available for all data)
- Side road traffic data (available for flag lit sites and a sample of unlit and fully lit sites)
- Intersection geometry (tee, Staggered Tee or Cross intersection)
- Right or Left turn provisions (KiwiRAP)
- Destination signs, advanced signing, and chevron boards (KiwiRAP)
- Number of Night, Day and Total crashes
- Crashes by injury severity
- Crashes by movement codes (types of crash)

2.3 Data analysis techniques

The Statistical analyses employed in the project used generalised linear modelling (GLM) and contingency table analysis.

3 Results

3.1 Results from Generalised Linear Modelling (GLM)

A Poisson multiplicative regression model was selected for modelling using the form:

N/T = e (a + b A + c B + d C+...) + ϵ

Where: N= number of night crashes (dependent variable)

T = Total number of crashes (day and night)

a, b, c and d are parameter estimates of the model

ϵ is the random error of the dependent variable

A, B, C etc are the independent variables which are being tested.

The structure of the model is log-linear, as in general the absolute size of impact of a crash countermeasure will depend on the size of the crash problem it is targeting. This situation is best described by such a model where the factors are assumed to act multiplicatively. A value of two standard deviations ($p<=0.05$) was adopted in rejecting the null hypothesis that the relevant variable has no impact on the night-to-total crash ratio.

Three samples were analysed in the GLM model;

1. All sites (Fully lit, flag lit, and unlit)

2. Flag lit and Unlit sites

3. Unlit sites

The modelling was carried out stepwise, by first looking at one variable models, then two variable models and finally three variable models in order to drill down to the factors with the most impact on safety. For the sake of brevity only results from the final three variable models are discussed in this paper.

All sites modelling provided the largest sample size (1610 sites) and not surprisingly provided most of the statistically significant results. It provided a broad brush overview of the night time benefits of lighting and other road furniture. The Flag lit and Unlit sites modelling allowed the introduction of variables relating to the number of lights per flag lit intersection. The Unlit sample allowed the impact of traffic signs and channelisation on night-time safety to be tested in an environment free of street lighting.

3.1.1 Model results using all intersections in database

The All Sites sample included the KiwiRAP Intersection Lighting categories 1, 2 & 3 where at least one crash had occurred. Flag lit and fully lit sites are grouped with the variable 'Lighting Present' to indicate an intersection. For all sites, the final three variable model provided the outputs shown in Table 2.

Variable name	Parameter Value	Implied result for night crash ratio
Lighting present	-0.203***	18% reduction where lighting present
"X" intersection	-0.296***	26% reduction if a cross junction
Destination signing	-0.157*	12% reduction where destination signing present

Table 2: Three variable model using the All Sites database

Note: * = No of times the parameter value exceeds standard error ** or more for statistical significance ($p<0.05$).

This strongly indicates a beneficial impact from lighting particularly at crossroads. It suggests that cross intersections have inherently fewer crashes at night than Tee intersections (a result confirmed in later contingency table analysis). The reasons behind this are not immediately clear but may relate to the increased turning movements at Tee intersections compared to

Cross intersections. The “Destination signing” variable while not reaching significance is still an interesting result. Reflectorised destination signing enhances visual guidance at isolated rural intersections. This result suggests its presence may favourably influence the night time crashes.

3.1.2 Model results using intersections which were either flag lit or unlit

When fully lit sites are excluded the results in Table 3 are obtained.

Variable name	Parameter Value	Implied result for night crash ratio
Lights per intersection	-0.136***	13% reduction per light (max=3)
“X” intersection	-0.274**	14% reduction if a cross junction relative to a Tee junction
Channelisation	-0.275*	14% reduction if channelisation present

Table 3: Three variable model using the All Sites database

Note: * = No of times the parameter value exceeds standard error ** or more for statistical significance (p<0.05).

The lighting variables “Intersection lit” and “Lights per intersection” proved to be the most robust[1] variables in all models. “Lights per intersection (a count of the luminaires at each site using Google Street View) was slightly more robust than “Intersection lit” (i.e. 1 if lit, 0 if unlit). Cross intersections again show a lower night to day crash ratio than Tee junctions. The presence of channelisation at these sites appears to be associated with a reduction in night crashes even when the effects of intersection type and the number of lights per intersection have been accounted for.

3.2 Results from contingency table analysis

3.2.1 Crash ratio changes by injury severity and lighting status

In this section the effect of a number of variables are explored using the Night to Day crash ratio as a measure of night time risk. Statistical significance is claimed at the 5% (p < 0.05) level using a Chi Squared test with Yates correction but probability levels between p <0.1 and p< 0.001 are shown in the tables. Crash reductions are expressed relative to a similar group of unlit rural intersections. Table 4 shows crash changes for injury crashes and all crashes including non-injury crashes at unlit, flag lit and fully lit rural intersections.

Injury and Non Injury Crashes	No of Sites	Day Crashes	Night Crashes	Night/Day crash ratio	Reduction	Significance p<
No Lighting	2853	875	408	0.47		
Flag Lighting	827	747	246	0.33	29%	0.001
Full lighting	490	829	263	0.32	32%	0.001
Injury Crashes Only	**No of Sites**	**Day Crashes**	**Night Crashes**	**Night/Day crash ratio**	**Reduction**	**Significance p<**
No Lighting	2857	374	152	0.406		

[1] In terms of the number of times the parameter value exceeds the standard deviation.

Flag Lighting	827	322	99	0.307	24%	0.1
Full lighting	490	322	89	0.276	32%	0.05

Table 4: Crash ratio changes for each injury crashes and all crashes including non-injury crashes at unlit, flag lit and fully lit rural intersections.

Through between the severity levels, flag lighting showed crash ratio reductions between 29% and 40% and full lighting showed crash ratio reductions of between 27% and 32%. Relatively similar reductions were found for fatal and serious crashes but these were not significant.

3.2.2 Lights per Intersection

Table 5 shows the effect on crashes of having more than one flag light present. The number of lights was determined from a manual search of the flag lit intersections using Google street view.

Influence of the number of flag lights per intersection (Google), All intersections						
All crashes	**No of Sites**	**Day Crashes**	**Night Crashes**	**Night/Day crash ratio**	**Reduction**	**Significance p<**
No lights	2858	876	408	0.47		
1 Flag light	613	461	172	0.37	20%	0.05
2 Flag lights	146	196	47	0.24	49%	0.001
3 Flag lights	57	82	24	0.29	37%	0.1
Influence of the number of flag lights per intersection (Google), T intersections						
	No of Sites	**Day Crashes**	**Night Crashes**	**Night/Day crash ratio**	**Reduction**	**Significance p<**
No lights	2602	718	351	0.49		
1 Flag light	553	391	150	0.38	22%	0.05
2 Flag lights	95	118	33	0.28	43%	0.01
3 Flag lights	46	61	17	0.28	43%	0.1
Influence of the number of flag lights per intersection (Google), X intersections						
	No of Sites	**Day Crashes**	**Night Crashes**	**Night/Day crash ratio**	**Reduction**	**Significance p<**
No lights	202	132	43	0.33		
1 Flag light	43	53	16	0.30	7%	
2+Flag lights	43	63	11	0.17	46%	

Table 5: Influence of the number of flag lights per intersection (from perusing Google street view)

Sites with at least two flag lights produced noticeably better safety results (e.g. 49%) than those with just one flag light (e.g. 20%) for all intersections and for Tee intersections and crossroads separately. Similar results which were not statistically significant were found for the smaller sample of staggered Tee intersections. The incremental safety benefit of having two flag lights at an intersection were similar for Tee intersections (22% to 43%), crossroads (7% to 46%) and staggered T intersections (34% to 48%).

3.2.3 Total Lumens

Information on the type and wattage of the lamps installed was available for 64% of the flag lit intersections, so that an estimate of the total light output (lumen package) could be made. For analysis the intersection total lumen were subdivided into “Low”, “Medium” and ”High” groups. The “Low” group corresponds to a single HPS 150w luminaire (<20kL), the “Medium” group to two HPS 150w or one 250w luminaire (<36 kL), and the “High” lumen group to everything above that.

The results (Table 6) suggest the best crash reductions come from the “Medium” total lumens group. That group showed a 44% crash reduction (statistically significant) when compared to crashes at the unlit sites. Neither the “High” nor the “Low” total lumens groups showed statistically significant results although in both cases the data recorded a reduction in crash ratio.

Total Lumens per intersection	No of Sites	Day Crashes	Night Crashes	Night/Day crash ratio	Crash Reduction	Significance p<
No lights	2857	875	408	0.47		
Low	301	217	80	0.37	21%	-
Medium	117	139	36	0.26	44%	0.01
High	52	80	27	0.34	28%	-

Table 6: Lumen groups at flag lit sites, using unlit sites as the “No lights” comparison group

3.2.4 Crash Movements

To identify which crash movements were influenced by Flag lighting three groupings of movement codes were defined.

1. Intersection type collisions involving two cars taking different paths through the intersection. These crash types are covered by the CAS movement codes G, H, J, K and L.

2. Single vehicle loss of control crashes. These crash types are covered by the CAS movement codes C and D. Although these are a major group of night time crashes previous studies have suggested that road lighting does little to reduce their frequency.

3. All other crash types including lane change, head on, collision with obstruction, rear end, manoeuvring and pedestrian crashes. These crash types are covered by the CAS movement codes of A, B, E, F, M, N, P and Q.

The results are shown in Table 7 and proved quite unambiguous:

Group1 - Intersection type crash movement codes (G, H,J,K and L)					
ITEM	**No of Sites**	**Day Crashes**	**Night Crashes**	**Night/Day ratio**	**Crash Reduction**
No Lighting	2857	318	54	0.17	0
Flag Lighting	827	400	63	0.16	7%
Full Lighting	490	468	89	0.19	-12%
Group 2 - Single Vehicle crash movement codes (C and D)					
ITEM	**No of Sites**	**Day Crashes**	**Night Crashes**	**Night/Day ratio**	**Crash Reduction**
No Lighting	2857	335	231	0.69	0
Flag Lighting	827	170	135	0.79	-15%
Full Lighting	490	125	108	0.86	-25%
Group 3 - General crash movement codes (A,B,E,F,M,N,P and Q)					
ITEM	**No of Sites**	**Day Crashes**	**Night Crashes**	**Night/Day ratio**	**Crash Reduction**
No Lighting	2857	260	128	0.49	0
Flag Lighting	827	221	60	0.27	45% *
Full Lighting	490	349	96	0.28	44%*

Table 7: Night/day crash ratios by intersection type and CAS movement code

The only crash movement group which showed a statistically significant reduction at lit sites was group 3 which comprised the head on, rear end, hit obstruction and pedestrian type crashes. Both flag lit and fully lit sites showed a sizable crash reduction (44% - 45%) with these types of crash and both results were statistically significant.

As in previous studies group 2, single vehicle lost control type crashes showed an increase under lighting of between 15 and 25%. While the result was not statistically significant taken with two previous studies it is further evidence that single vehicle loss of control crashes do not reduce where street lighting is provided.

The two vehicle intersection type crashes of group 1 showed little evidence of an improvement and none of the changes were statistically significant.

3.3 Warrants for flag lighting

Although New Zealand does not have a warrant for the installation of flag lighting it was very clear in reviewing the data for this study that a traffic volume based rationale already existing amongst the engineers responsible for the decision making. The number of luminaires per intersection was strongly related to a mix of both side road and main road flow. The purpose of this section is to extract relevant NZ state highway data which could in future help to form a future warrant or guideline for flag lighting.

The main road traffic volumes were available for most of the KiwiRAP intersection data. Traffic flow data is also available for side roads that are flag lit and for a sample of unlit and fully lit intersections. This data has been sorted in ascending order and presented as cumulative histograms in Figures 1 and 2 and as percentiles in Table 8. The selection process that applies in treating intersections with either flag lighting or with full lighting is clearly evident from these curves. It appears to be a function of both main road and side road flows.

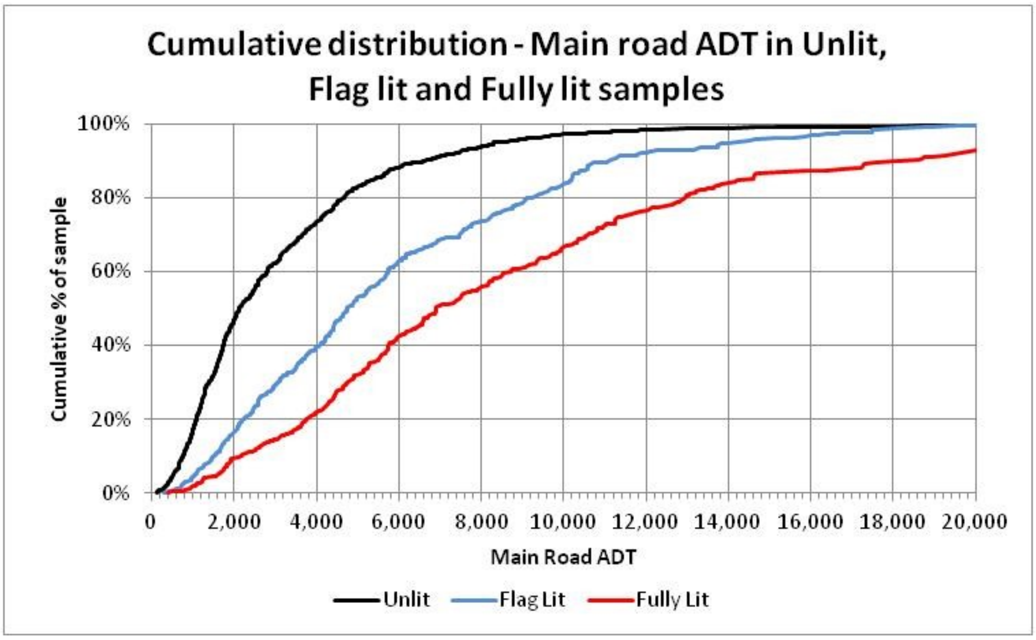

Figure 1: Cumulative Main road flows for unlit, flag lit and fully lit intersections

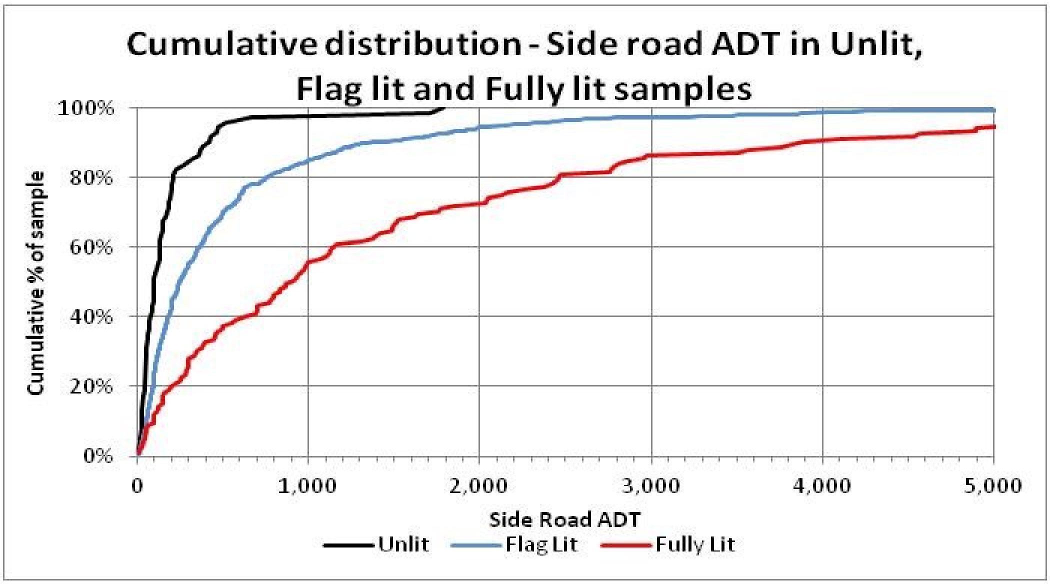

Figure 2: Cumulative Side road flows for unlit, flag lit and fully lit intersections

ADT percentile	Main Road (SH) ADT	Side Road ADT
5 th	1,049	27
15 th	1,890	67
50 th	4,745	242
85 th	10,230	998
95 th	14,198	2,123

Table 8: Table showing the cumulative percentile traffic volume for the current set of flag lit sites.

In Figure 3, side road and main road traffic flows are combined on one graph and by using different symbols the distribution of unlit, flag lit and fully lit sites are displayed.

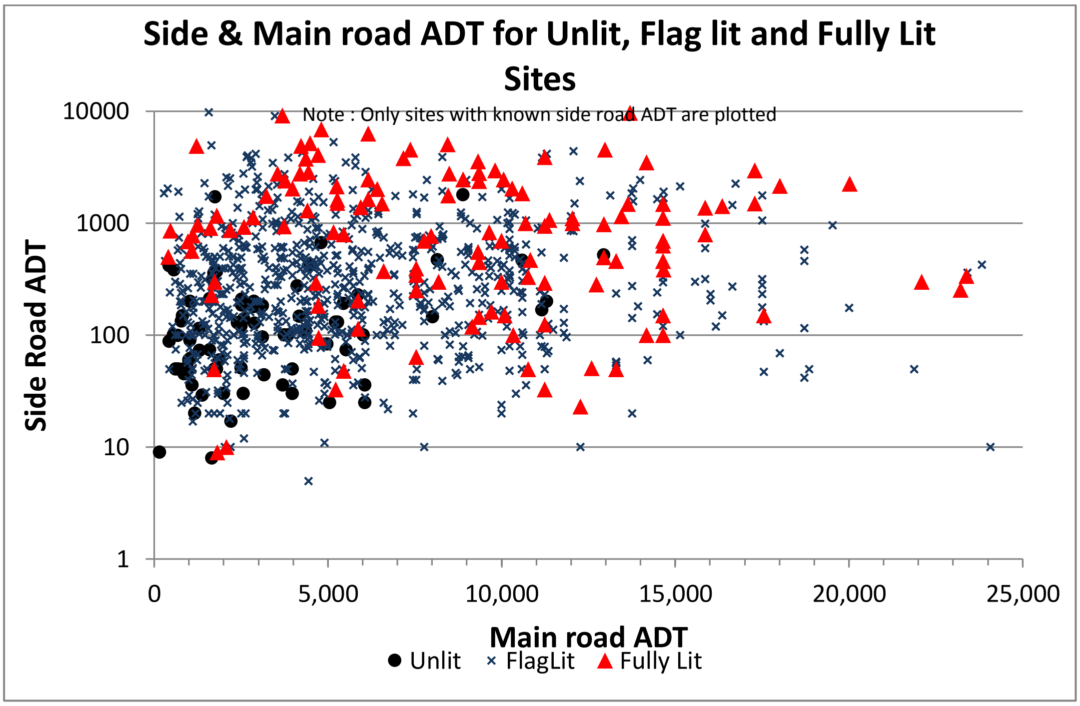

Figure 3: The main and side road flow for each unlit, flag lit and fully lit site

The graph shows the tendency for more highly trafficked sites to be fully lit or flag lit but there is considerable dispersion across the graph suggesting different implementation criteria may well apply in different areas. This suggests that more consistent practice could result by having a formal warrant criteria with a volume related component. Under a safe system approach road safety professionals have a responsibility to spend the road safety dollar as effectively as possible to reduce harm on our roads and flag lighting should be seen as a solution only when more passive measures are inadequate to preserve safety.

4 Conclusions

The study concluded that:

1. Flag lighting has a legitimate place in the New Zealand lighting hierarchy and if targeted at the most appropriate intersections also has the potential to be a highly cost beneficial road safety measure
2. Multiple flags lights (typically two) at an intersection achieve better safety than just one flag light.

3. In assessing the suitability of lights (including LED lights) for flag lighting the lumen package and the number of lights provided appear to be more important factors than the "flag" effect of any lighting.
4. Destination signing at intersections in itself may reduce night time crash and especially so where the intersection is unlit.
5. Channelization in conjunction with flag lighting or full lighting seems to provide additional night time safety improvements but channelization in the absence of any intersection lighting seems to reduce night time safety.
6. Chevron signs at intersections appeared to little influence proportion of crashes at night.
7. There was much variation in the traffic flows at the intersections where lighting was installed. This along with an economic imperative to install lighting only when other passive measures are inadequate indicates consideration of a national warrant for flag lighting.
8. Flag lighting should not be used as a countermeasure for loss of control/off road crashes and works best for rear end/obstruction type crashes.

5 Recommendations

It was recommended that the Transport Agency consider:

1. Providing advice to discourage channelisation at intersections which are not lit and the consideration of lighting and channelisation, together as a system prior to deciding whether to have both or just lighting.
2. Requiring the optimisation of passive intersection measures like destination signing, chevrons, and priority signage prior to considering lighting.
3. Discouraging the use of flag lighting to counteract loss of control off road crashes.
4. Developing guidance for flag lighting including consideration of:
   - the safety impact of the size of the total lumen package, related to the number of lights and their power, and its installation, running and maintenance costs.
   - the optimality of the passive measures already present at the intersection.
   - the traffic flow.
5. Including estimates of the safety impact of flag lighting in its Economic Evaluation Manual (EEM).

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