WHEN IS FLAG LIGHTING AN INTERSECTION A GOOD USE OF THE SAFETY DOLLAR?

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ABSTRACT

Flag lighting is lighting of an isolated intersection on an otherwise unlit route. The Transport Agency specifies that it is appropriate only after options to highlight the intersection with passive devices such as signs, road markings, and delineation have been implemented without satisfactory results.

New Zealand has no quantitative guidance for flag lighting. However, a recent project by the authors indicated that it can have considerable safety benefits. The project matched state highway Police reported crashes to a number of databases containing road infrastructure and vehicle flow information. Statistical analyses carried out suggested a safety impact similar to full lighting with both resulting in an around 30% reduction of the ratio of night crashes to day crashes. Two flag lights gave a higher reduction than a single light at all types of intersection. More than two lights rarely produced further crash reductions.

This paper uses the crash study results and real world costs to relate the safety when flag lighting is installed to the likely costs of installation and maintenance. It examines options for setting flag lighting guidance in terms of traffic flow, crash experience and a combination of both and suggests methods of doing so.

1 BACKGROUND

Flag lighting refers to lighting of an isolated intersection on an otherwise unlit route. According to the Transport Agency's M30 specification this should be considered only after all options to highlight the intersection with passive devices such as signs, road markings, and delineation have been explored and implemented. NZTA Technical Memorandum TM-2015 as referred to in M30 indicates that full isolated intersection lighting or flag lighting should be considered when:

- There is evidence of a high history of night time crashes
- There are raised islands that could be a hazard
- Pedestrians are often present (eg a community pick up point)
- When an intersection has limited visibility, complex geometry, confusing background, unusual traffic patterns
- In a highly trafficked tourist route where drivers may not be familiar with the road
- Where two main traffic routes meet or there is channelization on either road
- Where there are right turn movements or related turning bay

New Zealand has no quantitative warrant for flag lighting to supplement the above criteria. Some overseas jurisdictions, for instance the states of Ohio and Minnesota in the USA do have warrants. Figure 1 looks at side and main road flow for state highway intersections in New Zealand using one chart. Through the use of different symbols the distribution of unlit, flag lit and fully lit sites are displayed.

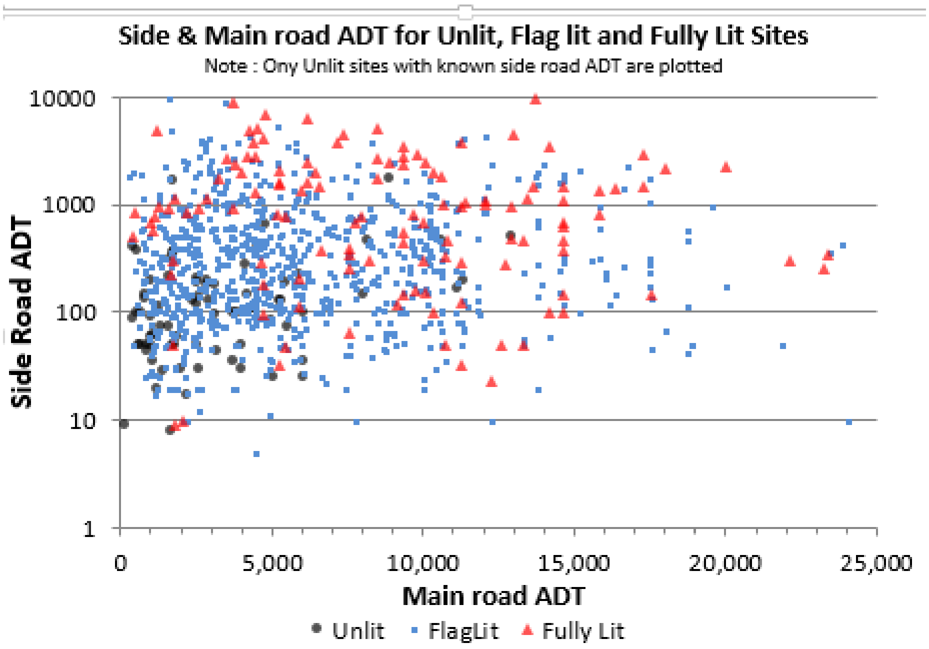

Figure 1: The Main and side road flow for each unlit, flag lit and fully lit site

Figure 1 shows the tendency for more highly trafficked sites to be fully lit or flag lit but there is considerable dispersion across the chart suggesting different implementation criteria may well apply in different areas. This suggests that more consistent practice could result by having formal warrant criteria with a volume related component, derived using rational means, to supplement the criteria in M30. 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. Flag lighting, as indicated in M30, should be seen as a solution only when more passive measures are inadequate to preserve safety.

2 THIS STUDY

New Zealand has recently carried out a project assessing the safety impact of flag lighting (Frith et al, 2016). Having the information gleaned from that project provides an opportunity to look at the cost effectiveness of flag lighting on state highways and consider what form such a warrant might take were one to be adopted.

The information available for this study includes, interalia,

- The crash information in the CAS system
- The rural intersection prediction equations in the EEM compendium
- Databases developed for the recent flag lighting research
- The results of the recent flag lighting research
- Existing warrants in other jurisdictions
- The method and costs found in the 2016 EEM and the associated compendium.
- Values researched in 2014 for the project on the economics of route lighting will be used but updated and with industry testing as appropriate.

The study analyses the social benefits arising from reduced night time crashes where flag lighting is installed matched against the likely costs of installation and maintenance. It examines with economic tools options for setting flag lighting warrants in terms of traffic flow, crash experience and a combination of both. It also examines whether there is a case for including any further variables in such a warrant or guideline. These could include; the presence of turning lanes, channelisation, and signs.

3 THE PLACE OF BENEFIT COST ANALYSIS IN THIS STUDY

The basis for road safety strategy in New Zealand is the Safe System approach whereby our actions are aimed at a final goal of a system without serious injury or death. This is similar to the “zero harm” basis of workplace safety. The ability to move towards this aim is constrained by the available funding. Thus, this funding must be rationed. Within this framework, benefit cost analysis is used as a rationing tool to fit the expenditure to this end into the available funding envelope which the Government can provide to the Transport Agency. The present system for the use of benefit cost analysis is found in the National Land Transport Plan (NLTP) framework for assessment for 2015[1]. Also, works are classified for BCR purposes into broad bands as shown in table 1.

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[1] https://www.pikb.co.nz/assessment-framework/benefit-and-cost-appraisal/

BCR range 1- 3	All activities with BCR greater than or equal to 1 and below 3 are prioritised in a single band for improvements to local roads, state highways, public transport and walking and cycling
BCR range 3 – 5	All activities with BCR greater than or equal to 3 and below 5 are prioritised in a single band for improvements to local roads, state highways, public transport and walking and cycling
BCR range > 5	All activities with BCR greater than or equal to 5 are prioritised in a single band for improvements to local roads, state highways, public transport and walking and cycling.

Table 1: BCR ranges used in the 2015 National Land Transport Programme

In addition, BCRs are not required for "individual minor improvements activities, when included in the minor improvements allocation". The benefit cost ratio is not the only criterion used to decide whether a road safety measure is actually implemented with other criteria including how it fits into a system of improvements, and the types and severity of crashes a project ameliorates coming into the decision making. In this work the BCR is used as an illustration of efficacy, not as a strict criterion and is supported by the Net Present Value criteria, which is measure of the difference between the benefits and costs.

4 THE CRASH BENEFITS OF FLAG LIGHTING

Results from recent New Zealand work on the safety aspects of flag lighting (Frith et al, 2016) show that flag lighting if targeted at the most appropriate intersections has the potential to be a highly beneficial road safety measure. In particular:

- Multiple flag lights at the intersection (typically 2) achieve a better safety performance than just a single flag light.
- Destination signing at intersections may in itself reduce night time crash and especially so where the intersection is unlit.
- Sites with flag lighting did not show any reduction in loss of control/off road crashes and achieved the greatest reduction with rear end/obstruction type crashes

The results from the study are shown in Tables 2 and 3 and can be summarised in the following four statements:

For Tee intersections

1. 23% crash reduction when installing one flag light
2. 40% crash reduction when installing 2 or 3 flag lights

For Cross intersections

1. no crash reduction when installing one flag light
2. 40% crash reduction when installing 2 or 3 flag lights

Tee Intersections	No of Sites	Day Crashes	Night Crashes)	Night/Day crash ratio	Crash Reduction	Statistical Significance p<
No lights	2601	716	351	0.49	N/A	N/A
1 Flag light	557	407	154	0.38	23%	0.05
2 Flag lights	90	110	34	0.31	37%	0.05
3 Flag lights	54	67	19	0.28	42%	0.1

Table 2: Crash reduction applicable to "T" intersections (includes non-injury crashes)

Cross Intersections	No of Sites	Day Crashes	Night Crashes (	Night/Day crash ratio	Crash Reduction	Statistical Significance
No lights	202	132	43	0.33	N/A	N/A
1 Flag light	43	53	18	0.34	-4%	Not significant.
2 + Flag lights	45	67	13	0.19	40%	Not significant

Table 3: Crash reduction applicable to "X" intersections ((includes non-injury crashes))

These results were obtained by estimating the percentage crash reductions expected from various configurations of flag lighting at T intersections and crossroads relative to no lighting. The flag lighting variables used to predict the percentage of crashes saved were:

- The geometry of the intersection (i.e. either a "T" or a "X" intersection)
- The number of flag lights provided (one, two or three)

5 METHOD

This study uses these results to examine the options for targeting the placement of flag lighting making use of benefit cost analysis (BCA) which uses as a measure the benefit to cost ratio (BCR). The number of crashes saved is the product of the percentage crash reduction and the expected number of night crashes which are estimated to occur without flag lighting. At a potential improvement site, there are two options for estimating the number of crashes without flag lighting:

1. Use the existing 5 (or 10) year crash record and assume it represents the long term mean value of crashes at each site. As the number of crashes per site needed to justify flag lighting is typically low (often less than one crash in 5 years) the random error from this method is very high, making its use somewhat unreliable.
2. Use main and side road traffic volumes as a predictor of the likely long term crash experience from:
    a. The NZTA Economic Evaluation Manual (EEM) Crash Estimation Compendium or
    b. The modified, crash linked, KiwiRAP database developed for the previous flag lighting research.

Given the inadequacy of option 1, the rest of this report relates to option 2. Section 6.3 of the Crash Estimation Compendium to the EEM provides a set of regression parameters to estimate the number of crashes expected at high-speed priority "T" and "X" junctions.

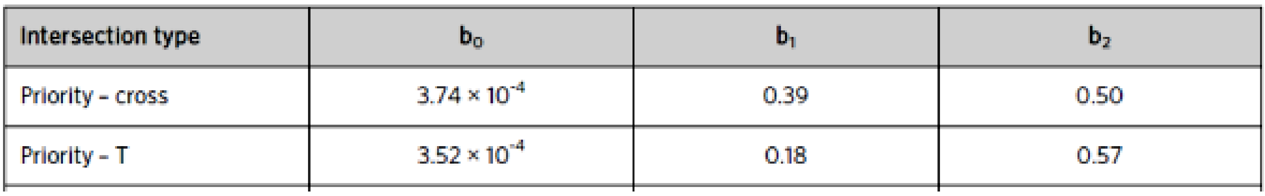
The general crash model is denoted by the equation $A_T = b_o \times Q_{major}^{b1} \times Q_{minor/side}^{b2}$ where:

A_T = reported injury crashes per year

Q_{major} = highest two way link volume for "X" junctions and the primary road volume for "T" junctions

$Q_{minor/side}$ = lowest two way link volume for "X" junctions[2] and the side road volume for "T" junctions

and bo, b1 and b2 are depicted in Table 4 taken from Table 17 of the EEM Crash Estimation Compendium, 2016 which relates to general high speed roads with speed limits greater than or equal to 80 km/hr.



Intersection type	b_0	b_1	b_2
Priority - cross	3.74×10^{-4}	0.39	0.50
Priority - T	3.52×10^{-4}	0.18	0.57

Table 4: Current parameter values from Table 17 of the EEM Crash Estimation Compendium, 2016. These values predict the number of injury crashes per year at an intersection.

6 RESULTS

Predictions using the EEM model

The predictions of the model are shown graphically in Figures 2 and 3 for main road traffic volumes of 1,800, 4,500 and 10,000 vpd. These correspond to the 15th%ile, the 50th%ile and the 85th%ile traffic volumes respectively from the KiwiRAP data of priority, State Highway intersections.

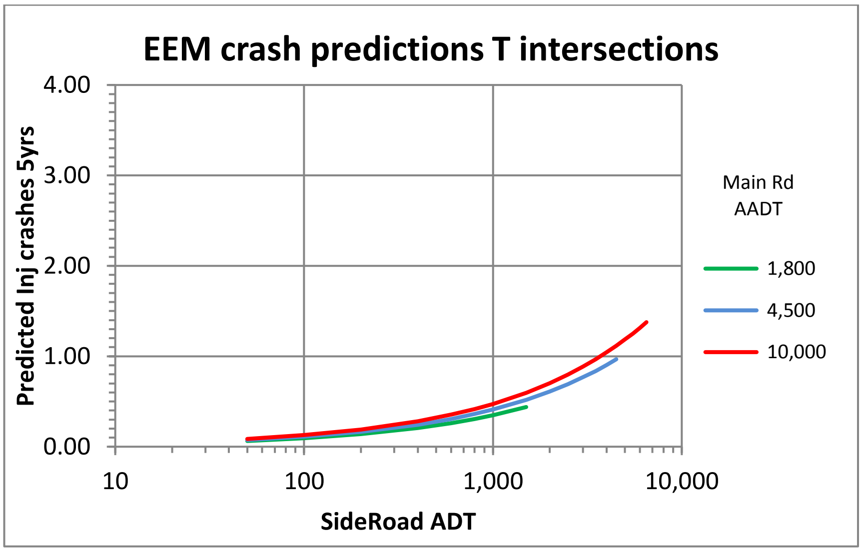


Figure 2: Predictions for injury crashes for high speed priority "T" junctions

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[2] Interpreted as the average two way flow of the two side roads

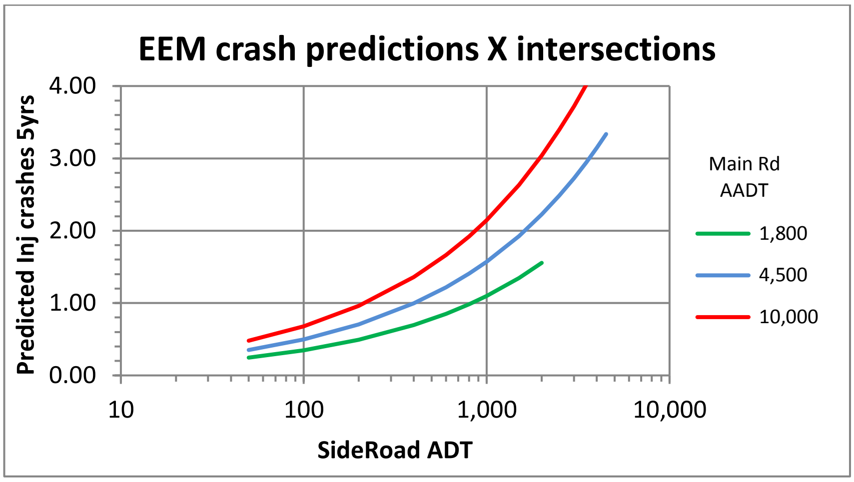

Figure 3: Predictions for injury crashes for high speed priority "X" intersections

Predictions using the KiwiRAP database

The modified KiwiRAP database contains 4,176 rural State Highway intersections with known main road flow and 981 (principally the flag lit sites) with known side road flow. The side road volume was obtained from the AMA "MobileRoad"[3] online facility. The KiwiRAP data was grouped by side road flow and is shown in Figures 4 and 5 as a series of points. The points in the "T" intersection graphs contain around 80 sites each and the "X" intersections charts around 15 sites each. Two EEM crash prediction curves are also shown in Figures 4[4] and 5. These represent curves based on main road flows at the 15%ile (1,800vpd) and 85%ile (10,000vpd) as found in the KiwiRAP data. It was expected that the points from KiwiRAP data would generally lie between the two EEM curves.

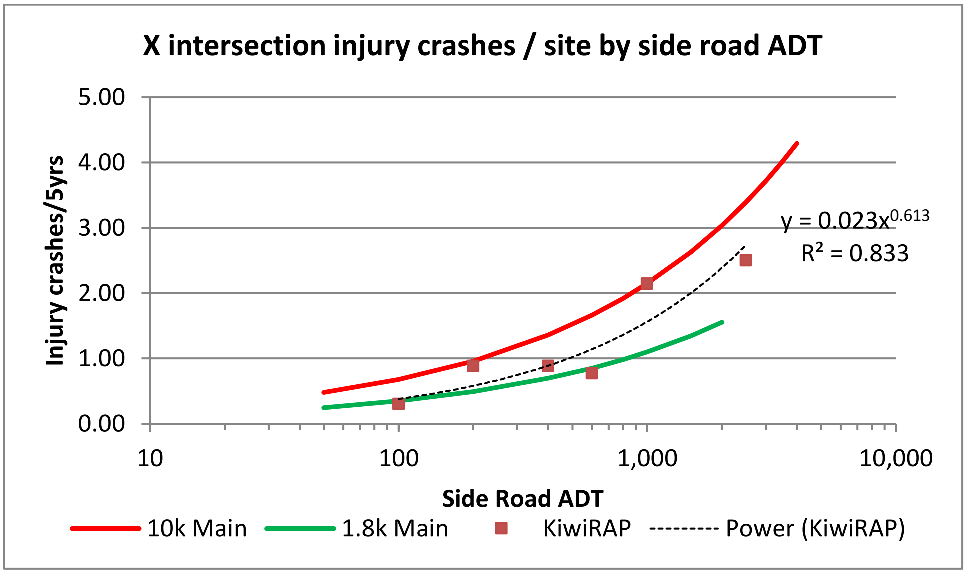

Figure 4: X intersections - EEM predictions for 1,800 and 10,000vpd main road flow overlaid with grouped data points from the KiwiRAP data

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[3] https://mobileroad.org/index.html Viewed 13/11/2016

[4] The central line is the best fit power curve to the red squares and has the equation shown on the chart

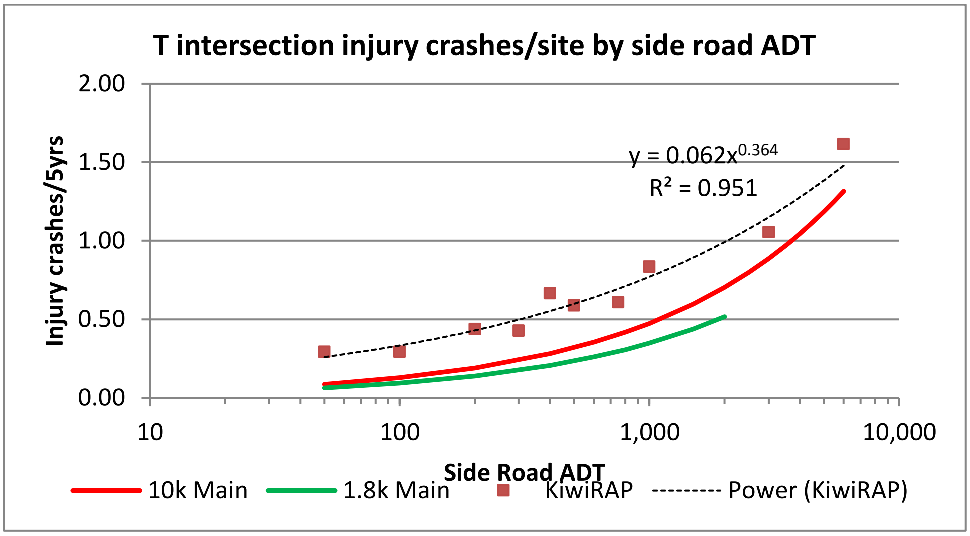

Figure 5: T intersections - EEM predictions for 1,800 and 10,000vpd Main road flow overlaid with grouped data points from the KiwiRAP data.

The EEM predictions and KiwiRAP data align well for “X” intersections (Figure 4) but not so well for “T” intersections (Figure 5) where the curve for KiwiRAP data is vertically shifted relative to the EEM prediction. The reason for the difference in “T” crash prediction is not clear but may in part relate to the updating process used by the EEM as the EEM equations are based on historical data.

The difference between the estimates from the KiwiRAP data and EEM predictions at T junctions is too big to ignore (approximately a factor of 2). The KiwiRAP data is very consistent across the range of side road volumes (R^2=0.95) and the “T” intersection crash data, larger and more robust than the “X” intersection data and does not align with the EEM predictions.

As an approximate solution, a multiplicative factor of 2 has been applied to the EEM predictions where “T” intersections are involved. This is a crude measure but by aligning KiwiRAP data with EEM predictions the more powerful EEM predictive relationships of main and side road flows can be used. Figure 6 shows how this adjustment aligns the two measures in the decision-critical, 100 vpd to 1,000 vpd side road flow range.

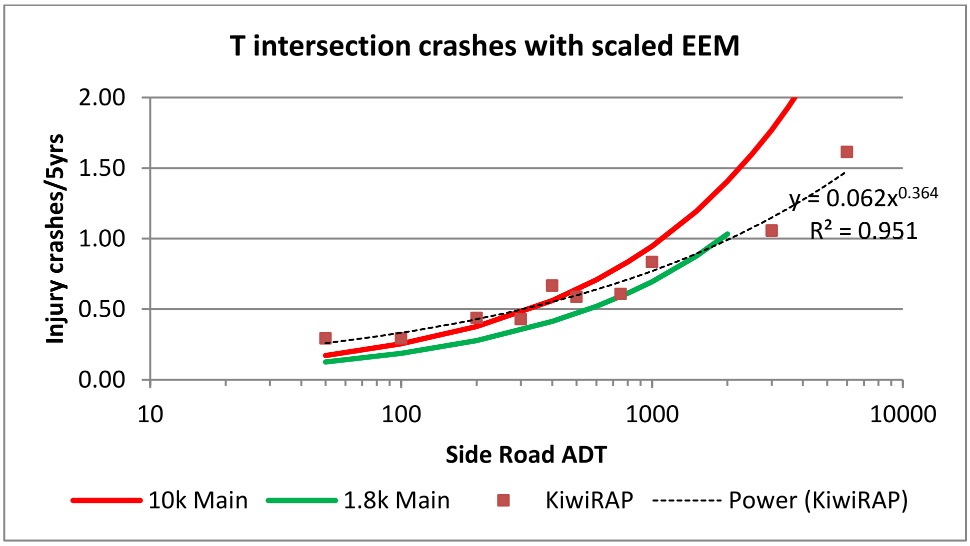

Figure 6: A repeat of Figure 4 but with the EEM predictions for T intersection crashes increased by a factor of 2 to improve alignment with KiwiRAP data points in the 100 – 1,000 vpd range.

Estimating Night Crashes

The analyses in the previous section refer to injury crash frequency both night and day. However, the savings expected from installing flag lighting are only relevant to night crashes so it is necessary to apply the volume related predictions to night crashes only. The KiwiRAP data identified the number of night and day crashes at unlit intersections by type of intersection as shown in Table 5.

Type	Total Crashes	Night Crashes	% Crashes at night
T Intersections	430	129	30%
X intersections	75	17	23%
Total	505	146	28.9%

Table 5: Number of reported Injury crashes in the KiwiRAP database at unlit, high speed, priority controlled, State Highway intersections for the period 2010 to 2014.

Using the figures in Table 5, the number of night time injury crashes at unlit, high speed, priority controlled intersections can be predicted by multiplying the T intersection crashes by 0.30 and the crossroad crashes by 0.23.

Estimating the social benefits of reducing crashes by installing flag lighting

In order to calculate benefit cost ratios estimates of the social costs of crashes are required. The basic unit in estimating the social cost of crashes is the "reported injury accident". The Economic Evaluation Manual provides guidance on the appropriate costs to use in EEM Table A6.5 (a)

The majority of sites for consideration for flag lighting would be "near rural" rather than "remote rural", would be priority intersections rather than uncontrolled and would be located within a 100km/h speed limit area. From the EEM the appropriate cost per reported injury accident (May 2015 prices) is;

- $565,000 for T intersections
- $575,000 for X intersections

The social value of the crashes expected to be saved is derived from the following relationship

Social Value of crash savings = *(predicted number of reported injury crashes at the site) x*

(predicted % of crashes at night) x

(predicted % night time crash savings) x

(cost per reported injury crash).

Some examples may be helpful.

Example 1: An unlit "T" intersection with 1 reported injury crash every 5 years. Using the equation above the potential social value of the crashes to be saved by flag lighting the intersection with a two light LED installation would be:

Social Value of cost savings (5yrs) = 1 x 30% x 40% x $565,000 = $67,800

Example 2: As for example 1 but with 1 reported crash (injury or non-injury) every 5 years.

Social Value[5] of cost savings (5yrs) = 1/2.48 x 30% x 40% x $565,000 = $27,338

Example 3: As for Example 1 but using traffic volumes to estimate crash numbers. Main road = 10,000vpd, side road = 200 vpd. EEM prediction equations with the KiwiRAP times 2 factor indicate 0.38 injury crashes / 5 years.

Social Value of cost savings (5yrs) = 0.38 x 30% x 40% x $565,000 = $25,764

Estimating the costs of installing and maintaining flag lighting

The costs of installing flag lighting are likely to vary considerably from location to location. Individual costs will be related to issues such as:

- The availability of power at the site and the amount of trenching or cabling required
- General remoteness of the site for access
- The availability of existing service poles to support flag lighting
- The need to use slip base poles
- Whether lighting needs extending to include a traffic island

Typical costs used in this analysis were obtained from a range of sources and are shown in Table 6.

Measure	Value	Units	Source[6]
Economic years to evaluate	40	yrs	EEM
Discount rate	6%		EEM
Economic life of pole	40	yrs	NZTA
Economic life of luminaire	20	yrs	NZTA
Operating hours / yr	4,250	hrs	NZTA
Electricity cost $ / kWh	$ 0.14		NZTA
System wattage of luminaire	136	watts	ADLT
Luminaire supply cost	$ 1,000.00	per luminaire	ADLT
Luminaire lumen output	14	K Lumens	ADLT
Column supply (10m, slip base)	$ 2,050.00	per column	CSP
Bracket arm (S&I)	$ 600.00	per pole	HS
Install column & luminaire	$ 1,150.00	per column	SM
Install new luminaire	$ 200.00	per luminaire	SM
Column/Pole electrical equip	$ 100.00	per column	SM
Cabling overhead (S & I)	$ 25.00	per metre	HS
Cabling underground (S&I)	$ 110.00	per metre	SM
Cable thrusts under road	$ 2,500.00	per crossing	HS

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[5] Note: The KiwiRAP sample of 3,400 crashes at SH, Open road, Intersections (excl roundabouts and signals) has 1 injury crash for every 2.48 injury or non injury crashes. This factor is used above to estimate the number of injury crashes.

[6] Meanings of acronyms. ADLT: Advanced Lighting Technologies, CSP: CSP Pacific, HS: Horizon Services, SM: Steve Muir (Connectics), MJ : Mike Jackett

Traffic management	$ 1,200.00	per day	SM
Design and supervision (High)	$ 1,500.00	per installation	SM
Design and supervision (Low)	$ 1,000.00	per installation	SM
Maintenance / pole (High)	$ 300.00	per year	MJ
Maintenance / pole (Low)	$ 100.00	per year	MJ

Table 6: Costs and other parameters used in the analysis

For the purposes of this evaluation two sets of costs have been calculated – a HIGH cost option using dedicated columns and undergrounded supply and a LOW cost option using existing service poles. A third MEDIUM cost is provided as a convenient reference point midway between the HIGH and LOW cost options. The costs are expressed in terms of;

- Capital costs related to the number of luminaires installed (e.g. lighting hardware and related installation costs)
- Capital costs which are a per installation cost (e.g. Traffic management, design & supervision, cable thrusts)
- Annual operating costs (electricity and maintenance costs)

The HIGH cost option is: A 136 watt LED installation using 10m dedicated street lighting columns with a slip base. Provision is made for 50m of underground cabling per column, one beneath road cable thrust, column electrical equipment, one day of traffic management, a design and supervision allowance of $1500, an annual maintenance budget of $300 per luminaire/column plus standard electricity charges (14c/kWHr).

The LOW cost option is: A 136 watt LED installation using outreach arms onto existing service poles. Provision is made for labour charges and standard pole electrical equipment but no provision for additional cabling and only ½ a day of traffic management. A design and supervision allowance of $1,000 is provided, as is an annual maintenance budget of $100 per luminaire. Standard electricity charges apply.

For both options the design luminaire is nominally replaced after twenty years. No other hardware is replaced in the economic evaluation period. Luminaire cleaning costs are assumed included in the annual maintenance budget. Using standard formulae, the costs are expressed in Present Value terms with a 6% discount rate and a 40 year evaluation term. Table 7 summarises the cost structures in terms of actual cost and Present Value costs.

	HIGH COST		MEDIUM COST		LOW COST	
	Cost/site	PV	Cost/site	PV	Cost/sit	PV
Capital costs	$24,800	$24,800	$14,900	$14,900	$5,000	$5,000
Annual Maintenance	$762	$11,463	$562	$8,454	$362	$5,444
Luminaire replacement*	$2,400	$748	$2,400	$748	$2,400	$748
Present Value of costs		**$37,011**		**$24,102**		**$11,192**

* After 20yrs service

Table 7: Cost structures applicable to a two luminaire flag light installation using the HIGH, MEDIUM and LOW cost options

Benefit cost analysis

The benefit cost analysis compares the Present Value of the benefit and cost streams

Benefit Cost Ratio (BCR) = Benefits / Costs ; Net Present Value (NPV) = Benefits minus Costs

Charts of BCR against traffic flow and crash numbers

Figures 7, 8 and 9 illustrate for T intersections and crossroads how the benefit cost ratio and NPV changes according to:

- the side road flow and main road flow, for a full range of side road flows and 5,000vpd main road flow chosen for illustrative purposes
- the number of reported (injury + non injury) crashes
- High, Medium and Low cost options in providing flag light lighting (Note LOW cost is the top curve, MEDIUM cost in the centre and HIGH cost the bottom curve)

Figure 7: BCR for T intersections with 1 and 2 flag lights

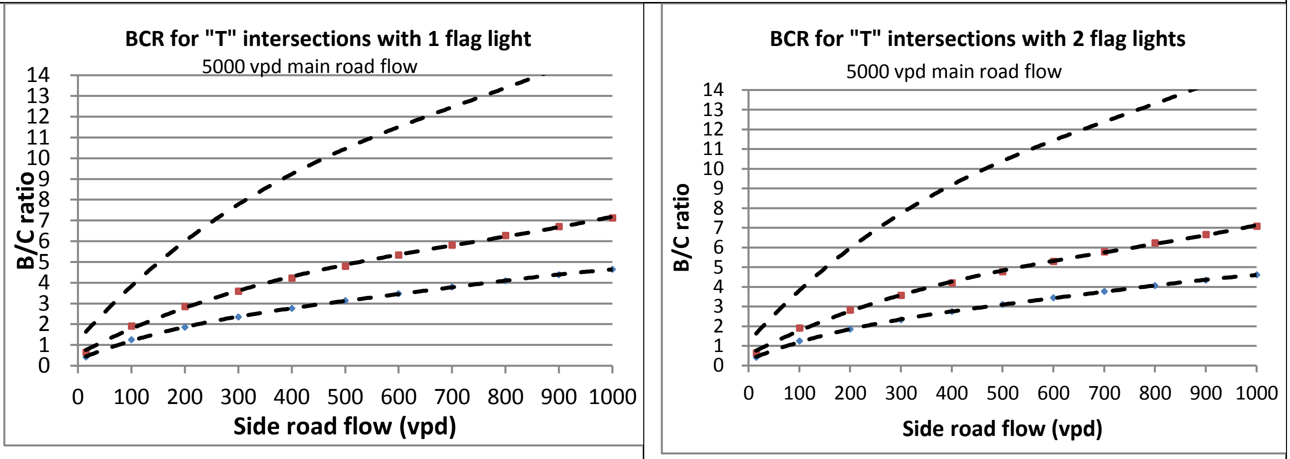


Figure 8: NPV for T intersections with 1 and 2 flag lights

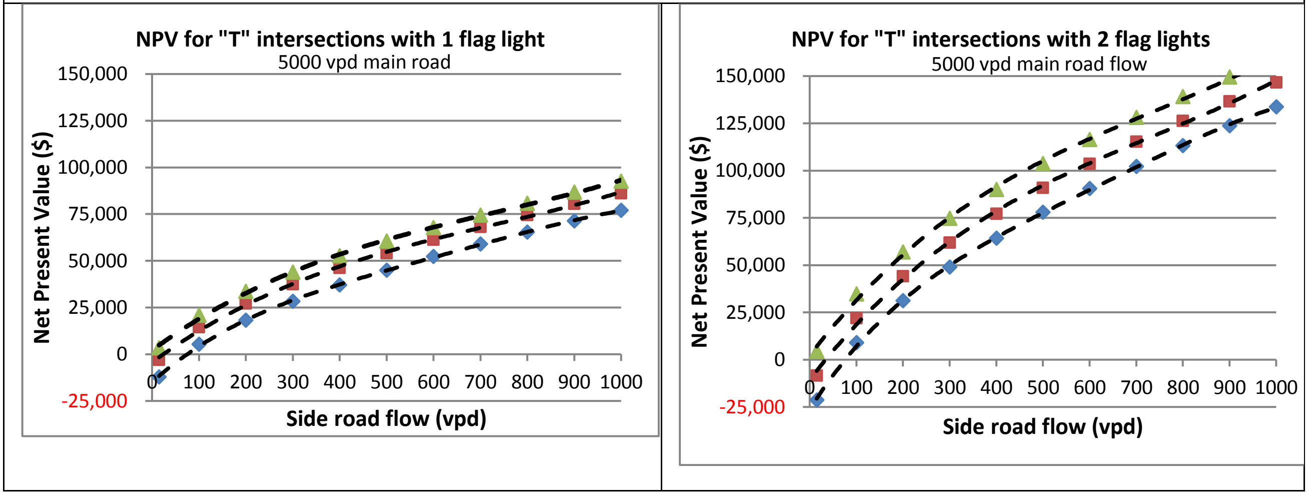
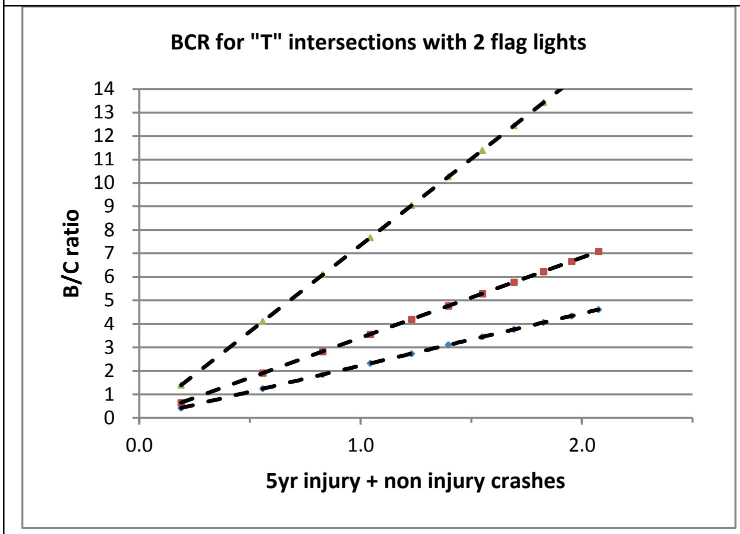


Figure 9: BCR related to crashes for T intersections with 2 flag lights



The chart for T intersections (Figure 7) indicates that where the main road flow is 5,000vpd, installations with either one or two flag lights will have a BCR over one when the side road flow exceeds 100 vpd. In deciding whether the additional cost of a two flag light installation has economic merit reference can be made to the NPV chart (Figure 8) which for side road flows over 100vpd shows a higher NPV for two flag light installations in preference to one flag light installations.

Putting these results together indicates that both one light and two light installations have positive economic benefits at side road flows over 100 vehicles per day but that the two flag light option produces the greatest return as evidenced by a higher NPV. Put simply the extra safety benefits expected from a two flag light option (40% crash reduction rather than 23%) outweigh the extra costs in providing two flag lights. These results apply to all cost options.

Figures 10 and 11 illustrate the position similarly regarding crossroads but for two lights only. No options were given for a single flag light at a "X" intersection because no safety benefits were detected for this option (see Table 3).

Figure 10: BCR for crossroads with 2 flag lights

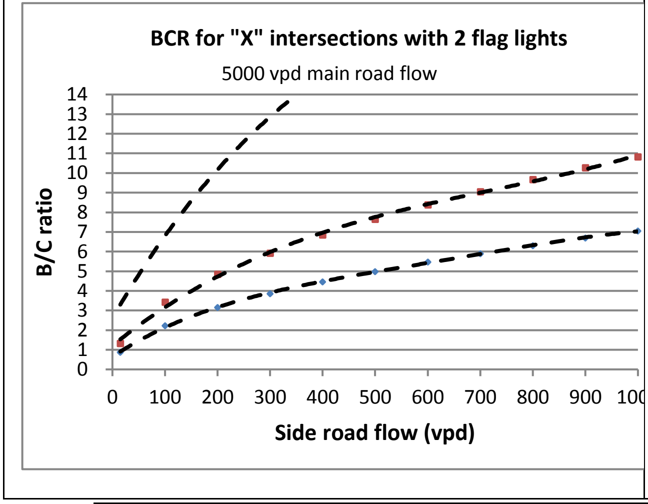
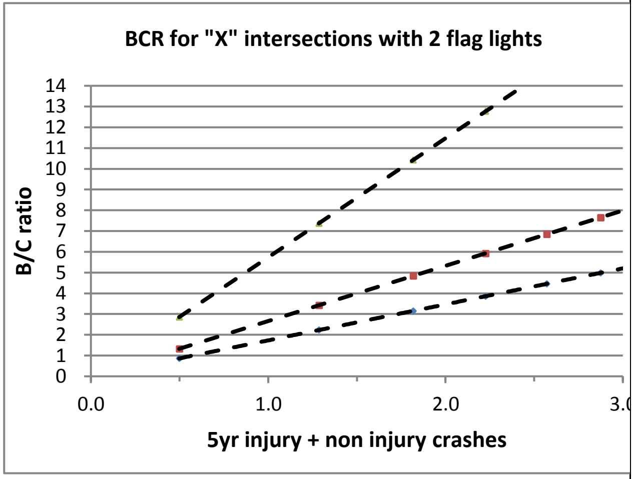


Figure 11: BCR related to crashes for crossroads with 2 flag lights



These charts show similar behaviour to those for the T intersections but the BCR values are slightly higher for the same side road flow because cross roads tend to have more crashes than "T" intersections. The BCR ratios are greater than one and when side road flows exceed 50 vpd.

In summary, it can be observed that:

- The Benefit cost ratios were predictably higher for the low cost options (existing poles) rather than the high cost options (lighting columns with undergrounded supply)
- At "T" intersections the benefit cost ratio for 1 and 2 light options were very similar. However, the higher NPV for the 2 light option suggests that it would be the preferred option economically.
- "X" intersections showed a higher benefit cost ratio than "T" intersections of the same traffic volume. This is because the "X" junctions tend to have a higher crash rate.

Taken together, the factors above suggest that flag lighting as well as being an effective crash countermeasure is also a cost-effective crash counter measure. The remaining challenge is to provide guidance to practitioners on where on the basis of traffic volume it is best to install flag lights.

Constant BCR curves

Using the EEM crash prediction equations (Table 4) modified by the KiwiRAP data it is possible to plot lines of constant crash numbers for varying side and main road flows. By establishing the critical number of crashes needed to produce a certain BCR these lines then become lines of constant BCR. The critical BCR values were established in the 2015 Land Transport Plan as BCR = 1, 3 and 5. Figures 12 and 13 show the main and side road traffic volumes required to achieve these predicted BCR values for the high and low cost flag lighting options.

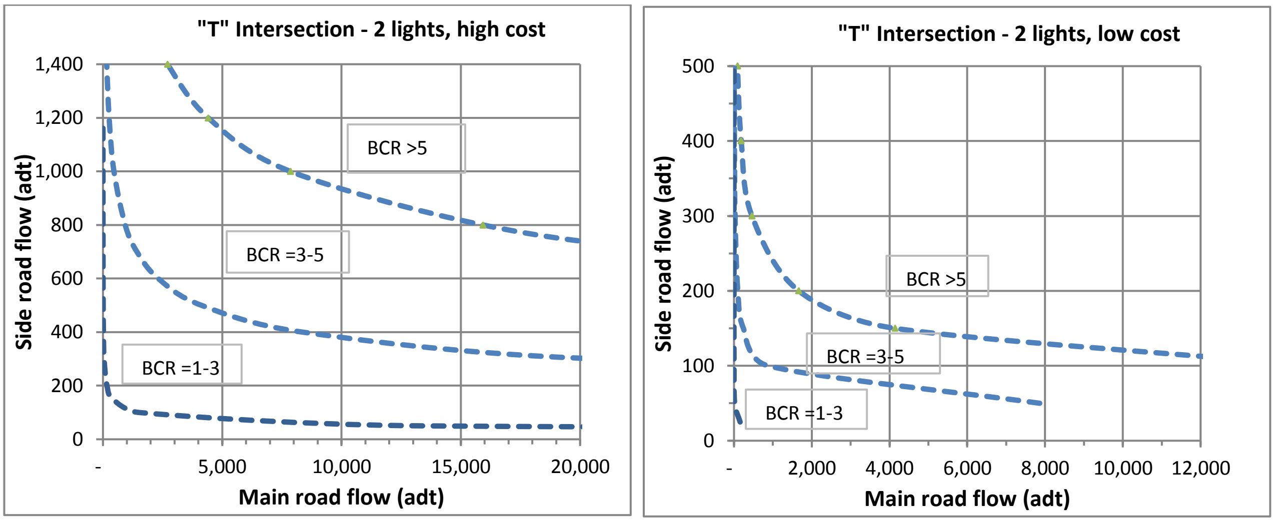


Figure 12: Main road flow vs. side road flow for "T" intersections indicating BCR ranges

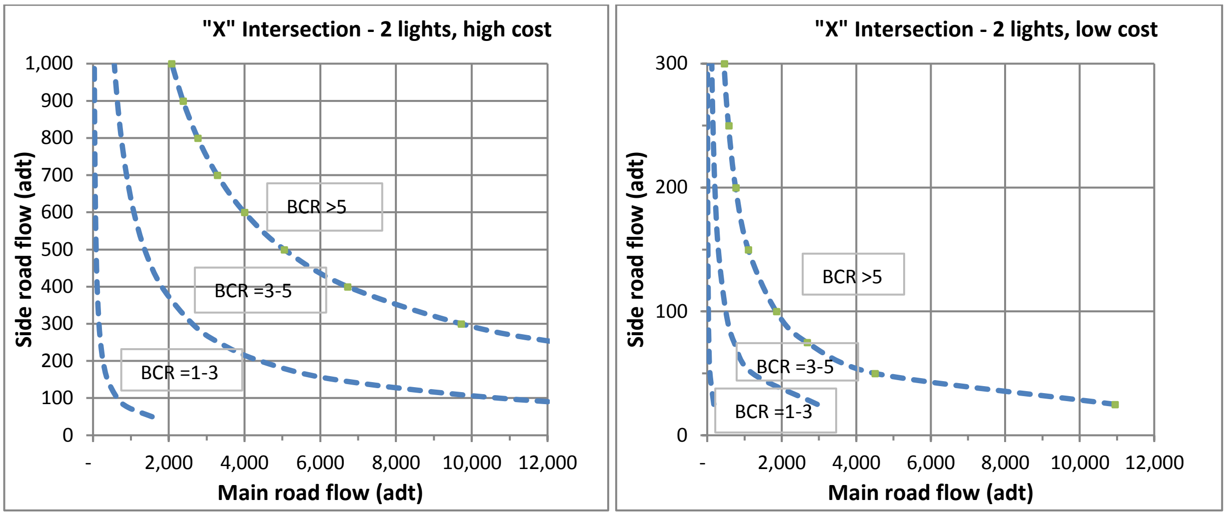


Figure 13: Main road flow vs. side road flow for crossroads indicating BCR ranges

The crash rate represented by each line in the figures above is given in Table 8 as the number of Injury plus Non injury crashes in 5 years.

	BCR=1	BCR=3	BCR=5
"T" intersection - high cost	0.45	1.35	2.25
"T" intersection - low cost (service poles)	0.14	0.41	0.68
"X" intersection - high cost	0.58	1.73	2.88
"X" intersection - low cost (service poles)	0.17	0.52	0.87

Table 8: The number of injury & non injury crashes in 5 years represented by the constant BCR lines in figures 12 & 13

As can be seen from the charts, BCRs in the range 1-3 can be associated with cases of very small main and side road ADTs. Given those small flows, and the likelihood of commensurately small numbers of crashes, although the BCR may be greater than 1, the associated NPV of the benefits may be small.

7 DISCUSSION

The analyses from this study suggest the following be taken account of in guidance to supplement that guidance in M30

- Decisions on the installation of flag lighting should be in accordance with the procedures in the National Land Transport Programme. They should take into account safety benefits and any other non-safety benefits which may accrue from installing the lights
- The priority of flag lighting works in a safety works programme should be consistent with the BCR classification of Table 1. Flag lighting proposals should also take into account the NPV at the pre-proposal stage with proposals of higher NPV taking precedence over mutually exclusive projects with similar BCRs but lower NPVs.
- Charts of the genre exemplified in Figures 12 and 13 could be used as simple screening tools to assist practitioners in ranking proposals

- Sites with two luminaires at the intersection tended to show a better safety and economic performance than sites with only a single light.
- At "X" intersections two lights should be regarded as the minimum. There was no safety improvement identified at "X" intersections where there was only one light.

8 RECOMMENDATION

It is recommended that guidance based the information presented in this report be prepared for inclusion in the appropriate Transport Agency guidance documents

REFERENCES

Frith, William et al (2016) An investigation into the safety benefits of Flag Lighting at New Zealand State Highway intersections. Presentation at the NZTA/NZIHT Conference Dunedin