Intersection transformation and the Level of Safety Service indicator

Category: *Collaboration to deliver a safer system in transportation*

Authors:

Peter Cockrem
BE(Hons)(First Class)(Civil) GIPENZ
Graduate Transportation Engineer, Abley Transportation Consultants Ltd
Contact: peter.cockrem@abley.com

Tim Hughes
National Traffic and Safety Engineer, NZTA
Contact: tim.hughes@nzta.govt.nz

Paul Durdin
BE(Hons), MIPENZ, CPEng
Director, Abley Transportation Consultants
Contact: paul@abley.com

ABSTRACT

Level of Safety Service is a measure of actual intersection safety performance relative to that expected based on a reference set of New Zealand intersections. This technical note describes a collaborative project to extend earlier New Zealand intersection prioritisation work, using concepts from a North American implementation, for inclusion in the New Zealand Transport Agency High Risk Intersections Guide.

The Level of Safety Service approach incorporates historic crash data, intersection configuration and control, the speed environment, and traffic flows. Intersections that perform poorly compared to expected performance will often have inherent flaws that can be readily mitigated, such as approach speed or sight distance problems. Those that perform as well or better than most similar intersections are likely to require more extensive work to deliver safety improvements, such as transformation from priority control to a roundabout.

New elements of this work include addressing problems associated with asymmetry in the distribution of crashes through use of quantile regression to determine the LoSS category boundaries, using LoSS to compare different forms of intersection control, and using New Zealand intersection data.

The Level of Safety Service indicator provides a tool that enables practitioners to identify those intersections where road safety benefits are most likely to be realised, and indicate what type of improvement is most appropriate. The indicator is likely to have a significant impact on how transport professionals prioritise safety improvement budgets and work.

INTRODUCTION

There is extensive literature covering the identification of dangerous intersections and prediction of crashes, as discussed in reviews internationally (Lord & Mannering, 2010) and in New Zealand (Turner & Wood, 2009). The High Risk Intersections Guide project seeks to guide road safety practitioners in applying aspects of this research to New Zealand.

The High Risk Intersections Guide is a flagship initiative of the government's Safer Journeys strategy implementation. It is intended to help national, regional and local Road Controlling Authorities to identify dangerous intersections and make decisions about improvements that will produce a safer transportation system, while delivering better value for money than the current approach. Road safety and value for money are two of the three key focus areas of the Ministry of Transport's over-arching policy direction for the transport sector, Connecting New Zealand.

Road safety improvements have historically been targeted at 'blackspots' – roads and intersections that have the highest number of crashes (Land Transport NZ, 2004). However, many of these locations have high crash rates due to particularly high traffic volumes, rather than engineering issues, and it is becoming increasingly difficult to obtain further safety improvements using this approach. The road fatality rate per billion vehicle kilometres travelled reduced 53% in the decade from 1990 to 2000. However, in the following decade from 2000 to 2010, the reduction was only 29% (Ministry of Transport, 2012).

An alternative way of targeting high risk intersections looks at the crash rate per vehicle using the intersection. Intersections that have both a high crash rate per vehicle, and a moderate to high total crash rate, are a higher priority than those with only a high total crash rate. If funding was unlimited and all intersections could be improved at once, this would be sufficient information. Unfortunately it does not show which of these intersections will be very expensive or very economical to make safer.

This is the reason for using the Level of Safety Service (LoSS) indicator. LoSS shows how well a particular intersection is performing relative to intersections of the same form and speed environment. A high risk intersection will be a lot cheaper to improve if it is performing much worse than similar intersections, compared to if it is performing much better than expected.

Consider a high risk urban priority-controlled crossroads: if it is performing much worse than most similar intersections it is likely to be unusually flawed, with problems that can be relatively readily improved such as approach speed or sight distance. If, on the other hand, it is high risk despite performing better than most comparable intersections, that suggests it is an inappropriate intersection form for its location and safety improvements will only come from more expensive intervention, such as transformation to a roundabout.

A range of approaches have been used internationally and in New Zealand to determine what a 'normal' crash rate is for any particular intersection. These range from very straightforward models using only intersecting leg traffic flow data (Tanner, 1953), more detailed models using separate turning movement flows, approach speeds and sight distances (Turner & Roozenburg, 2007), through to very sophisticated models predicting different crash types separately and additionally considering a wide range of contributing characteristics including gradient, lane number and alignment, and road hierarchy (Koch & Mannering, 1996).

The approach taken for LoSS is relatively straightforward and requires only the intersection control (priority, roundabout, signals), speed environment ('urban' <80kph, 'rural' ≥80kph), and traffic flows on each intersecting leg (two-way average daily traffic). Detailed explanatory factors such as sight distance and approach speed are not necessary for identifying whether an intersection is more or less dangerous than normal. Crash prediction models incorporating greater detail are included in the NZTA Economic Evaluation Manual (EEM) and can be used for predicting the safety benefits of proposed changes to intersections at the detailed design stage (NZTA, 2010).

A conceptual framework for using LoSS to identify dangerous sections of road was formalised by Kononov and Allery (2003) in North America, under the name Level of Service of Safety. This was included as a performance measure in the Highway Safety Manual (AASHTO, 2010), and extended to intersections. Ideas from this publication were drawn on to develop existing work by Durdin (2010) into LoSS as it now exists in the High Risk Intersections Guide.

HISTORY OF LEVEL OF SAFETY SERVICE IN NEW ZEALAND

The precursor to the High Risk Intersections Guide version of Level of Safety Service is in an intersection safety prioritisation study by Durdin (2010), where the EEM crash prediction models were used to predict crash rates at 1,100 Christchurch intersections. This study explored several tests to prioritise intersections based on how much better or worse their actual crash rate was than that predicted, with analysis and presentation using a Geographical Information System (GIS).

Performance tests considered for intersection prioritisation in this study included:

- Total actual crash rate. This is inappropriate as higher crash rates are expected even for well-performing intersections with higher flows, so it underestimates the improvement possible at less busy intersections.
- Absolute difference between actual and predicted crash rates. This is better, but crash rates relative to traffic volumes are heteroscedastic, meaning that the variance in crash rate increases as traffic volumes increase. Again, this would misleadingly emphasise the busiest intersections.
- Ratio of actual crash rate to predicted crash rate. This is an improvement as it addresses the heteroscedasticity, although the random variation associated with low crash counts can mean high ratios at the low end of the range as less meaningful than at the high end.
- Ratio combined with Geoffrey E. Havers (GEH) statistic. The GEH statistic is an empirical formula similar to a chi-squared statistical test and is commonly used in traffic engineering to compare two sets of data. It is designed to place greater weight on larger differences between observed and predicted data at sites with a high observation count (Ortuzar & Willumsen, 2011). This was ultimately adopted in modified form by Durdin (2010).

The intersection prioritisation objective and process of comparing actual to predicted performance has been carried forward from this study. The North American work has been drawn on for the LoSS name and the concept of determining level of service categories at the same stage that the crash prediction model is determined.

DEVELOPMENT OF LEVEL OF SAFETY SERVICE

Level of Safety Service as applied in New Zealand differs from that used in North America in a number of ways.

Kononov & Allery (2003) used four level of service categories (I to IV) to prioritise their intersections, with the three divisions being the negative binomial regression line, and the lines 1.5 standard deviations above and below this line. The occurrence of crashes at any particular intersection can be considered to be a Poisson process (Nicholson & Wong, 1993) with a crash rate λ, as long as the time period considered is longer than any daily or seasonal variation. Where a large group of intersections is considered, as for any particular product of flow range, the total number of crashes occurring becomes negative binomially distributed rather than Poisson. This is because the variance is greater than the mean (Rodriguez, 2007) as crashes are not independent as some intersections are safer than others.

However, the negative binomial distribution is not symmetrical, so placing the level of service divisions equal distances above and below the mean produces two significant undesirable effects. First, it means that each LoSS category can contain quite different proportions of the reference intersection sample, varying for different traffic volumes and different intersection control forms. Second, it can lead to low traffic volume intersections with zero crashes being assigned an inappropriate category, because if 1.5 standard deviations is larger than the mean then the LoSS I-II division intersects the x axis.

These two problems, have been addressed in the New Zealand implementation of LoSS by using 30th, 50th, 70th and 90th percentile lines to create the LoSS category divisions. These percentile lines can be asymmetric about the 50th percentile line, provide predictable proportions of intersections in each category, and do a better job of ensuring that intersections with zero crashes are assigned LoSS I.

Additionally, a fifth category has been added to highlight the very worst 10% of intersections, and New Zealand intersection data has been used to customise the ratings to local conditions.

IMPLEMENTATION OF LOSS FOR THE HIGH RISK INTERSECTIONS GUIDE

Crash data from the NZTA Crash Analysis System (CAS) was combined with intersection leg flow data from a variety of sources to determine the typical crash rates at different types of New Zealand intersections. Urban road flow data was obtained in GIS form for Auckland, Wellington and Christchurch. In rural areas, extensive flow data is available only for State Highways, so a selection of State Highway intersections were selected and side road flows extracted from CAS.

Past work has shown that the crash rate at an intersection is highly correlated with the number of potential vehicle conflicts (Tanner, 1953), which depends on through and turning movements. It is resource-intensive to collect this data and in New Zealand this level of detail is generally limited to peak-hour counts at select urban intersections. Data on the two-way traffic on road links is much more readily available, and can be used as a proxy for vehicle conflicts, so is more appropriate for a tool intended for national use.

Urban priority crossroad intersection data points plotted with injury crash rate against their calculated 'product of flow' in Figure 1. As shown there is an approximately linear relationship between crash rate and product of flow, with the 50^{th} percentile line representing the boundary between LoSS II and III. This figure also shows that there is considerable variance: intersections with the same product of flow range can vary from very safe, in the green LoSS I band, to dangerous in the black LoSS V band.

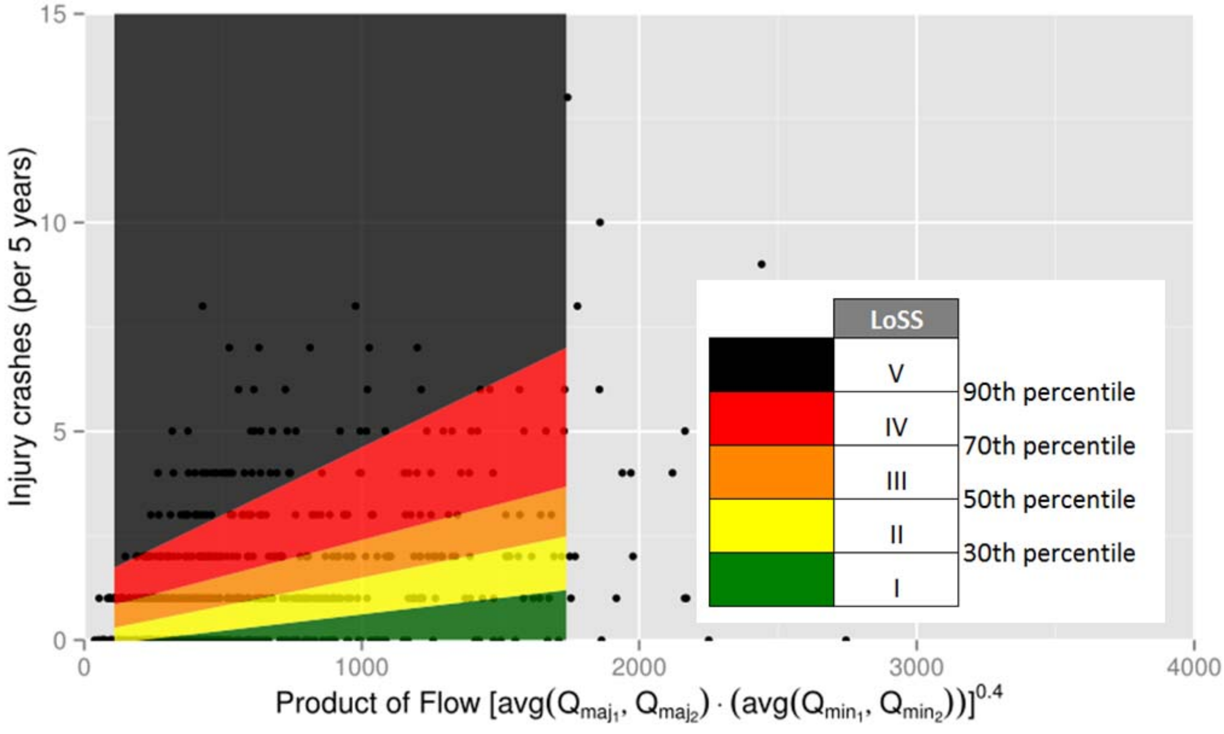

Figure 1. Crash rates at urban priority crossroads overlaid with Level of Safety Service colour bands.

Traffic volumes on each road connecting to an intersection were converted to a single number, termed the 'Product of Flow' in this work, using an approach found to give an approximately linear relationship with crash rates based on work originally done by Tanner (1953).

REFINEMENT OF LoSS

Two main changes have been made to the LoSS definition since its initial inclusion in the Draft High Risk Intersections Guide.

First, it was determined that for crossroads intersections a considerably better correlation between crash rate and product of flow is obtained if the formula is defined using an average of the minor road flows ($r^2 = 0.445$), rather than the minimum ($r^2 = 0.225$).

The formula has been changed from:

$$Product\ of\ Flow = \left(average\left(Q_{major_1}, Q_{major_2}\right) \cdot minimum\left(Q_{minor_1}, Q_{minor_2}\right)\right)^{0.4}$$

to:

$$Product\ of\ Flow = \left(average\left(Q_{major_1}, Q_{major_2}\right) \cdot average\left(Q_{minor_1}, Q_{minor_2}\right)\right)^{0.4}$$

where Q_{major_1} and Q_{major_2} are the two-way average annual daily traffic (AADT) flows on the main road, and Q_{minor_1} and Q_{minor_2} are the two-way AADT flows on the minor road. For a 3-leg T intersection the same formula is applied with $Q_{minor_2} = 0$.

Second, the means of determining the LoSS boundary percentile lines was made considerably more statistically rigorous. The preliminary approach had involved fitting a least-squares linear regression line through the mean of different subsets of the data (e.g. the 90th percentile line was determined as the mean regression line through the worst 20% of the data). The refined approach uses a quantile regression process (Koenker, 2005) implemented in R[1] to fit these percentile lines based on the full dataset.

Limitations

As with any form of statistical analysis, sample size was very important for this study. Traffic flow data for urban roads was more readily available and recent than that for rural intersections, and rural traffic signals and roundabouts are comparatively rare in New Zealand, so the results for urban intersections are more statistically certain.

PRIORITISING INTERSECTIONS USING LoSS

The Level of Safety Service of a real-world intersection can be determined conveniently based on just two pieces of data: AADT flows on each leg, and the number of crashes in a five year period.

The traffic flows are converted into a product of flow using the formula mentioned in the previous section, and the LoSS can then be looked up on the chart for that type of intersection in the High Risk Intersections Guide, like that in Figure 1.

As discussed in the introduction, collective risk (total crashes) and personal risk (crashes per vehicle) can be used to determine which intersections are high risk, though without giving any indication of the cost of reducing this risk. The Level of Safety Service indicator adds this extra dimension.

As Figure 2 shows, most intersections with high collective and personal risk (top right corner) generally also have very poor LoSS. This means collective and personal risk is generally sufficient for targeting the very worst intersections. However, some intersections that have only high personal risk (top left) or collective risk (bottom right) can have cost-effective improvements made, and these are only highlighted by adding the LoSS indicator, as annotated on the figure.

COMPARING INTERSECTION FORMS USING LoSS

An additional outcome of this work is the ability to directly compare the crash rates at intersections with different forms of control. Figure 3 shows an example of this for urban T intersections. The median regression line is shown as a solid line and the interval from the 30th to 70th percentiles is shaded in the same colour.

This allows interesting observations to be made, such as the higher gradient of the median line for priority control compared to other forms, and its greater rate of increase of variance. There is also considerable overlap of the better and worse examples of different types of intersection. These figures help to provide some indication of the different benefits that can be expected from intersection improvements compared to those from transformation, and are included in the High Risk Intersections Guide for urban and rural crossroads and T intersections.

[1] The R Project for Statistical Computing, http://www.r-project.org

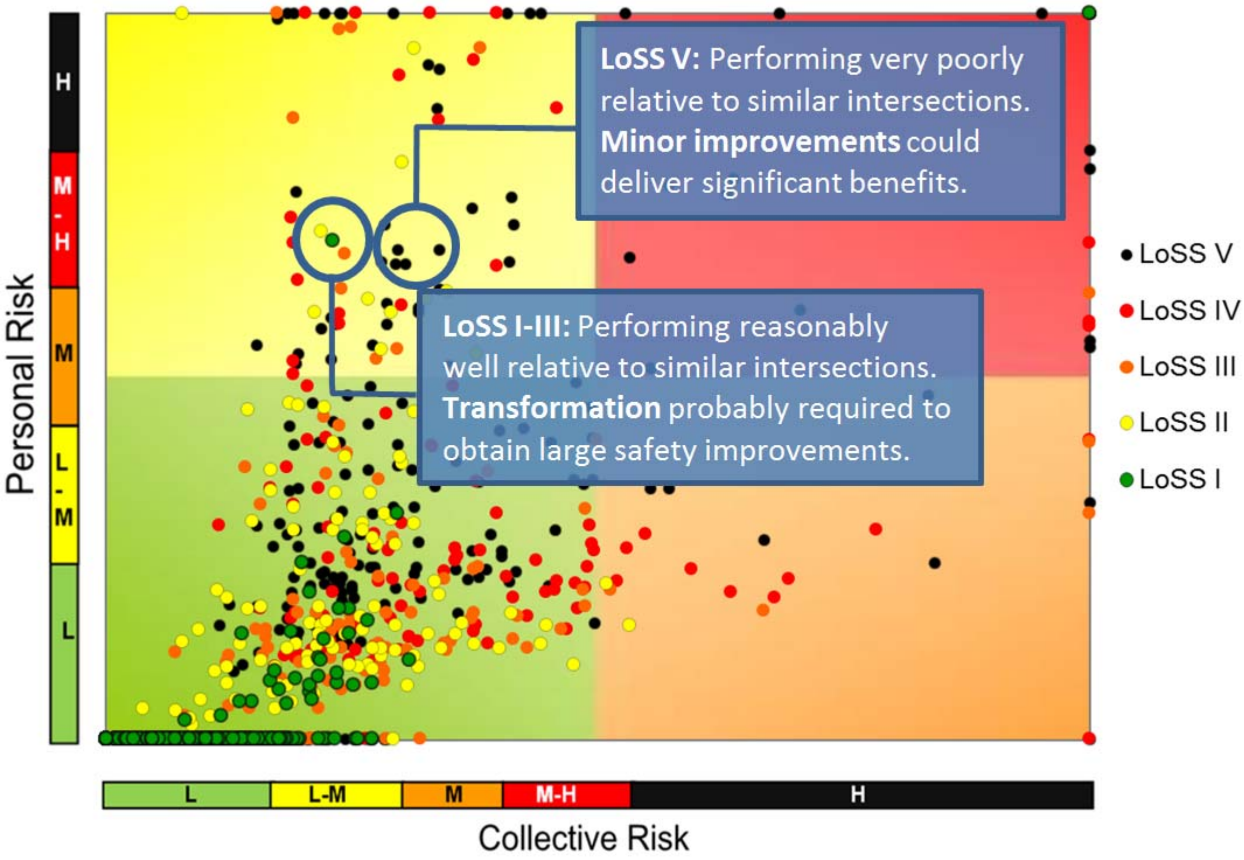

Figure 2. Urban Auckland intersection data points plotted in terms of collective risk (total) and personal risk (per user), with the chart enhanced by colour-coding points according to Level of Safety Service rating.

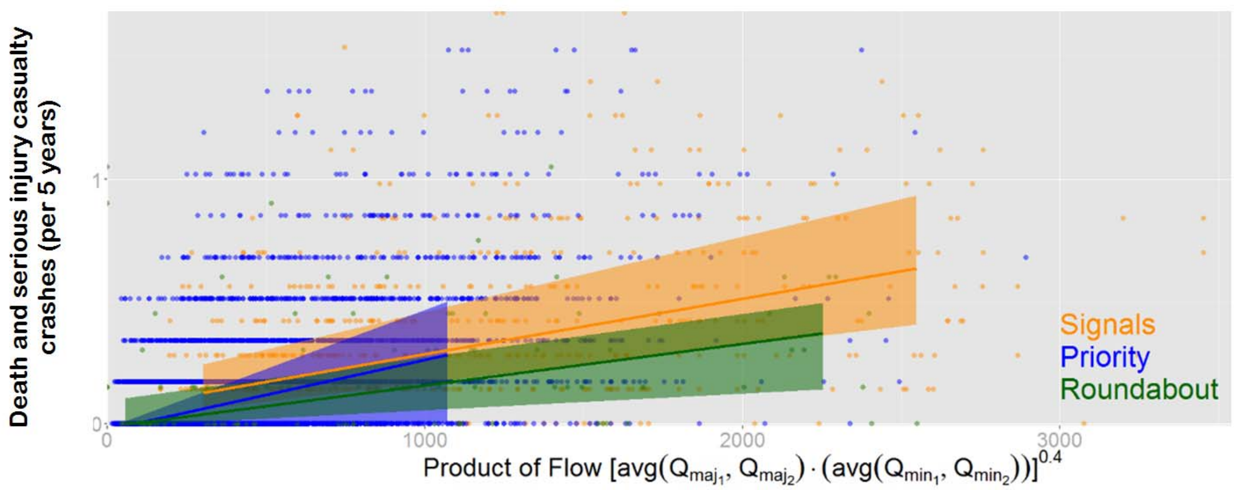

Figure 3. Comparison of crash rates at urban T intersections with different intersection control methods.

EXTENDING LOSS

The linear quantile regression approach to categorising intersection performance used here could be extended to non-linear quantile regression with functions such as exponential, logarithmic or power relationships, or nonparametric quantile regression (Takeuchi, Le, Sears, & Smola, 2005) where sufficient data is available to reduce the effect of outliers and data gaps.

This could lead to investigation of the nature of the relationships between crash rate and intersection vehicle conflicts near the upper and lower bounds of crash rates for each intersection form. This type of analysis has been applied to the field of ecology (Cade & Noon, 2003), where a measured variable often depends on a large number of measured and unmeasured controlling variables, which could be considered similar to the case of intersections.

CONCLUSION

The Level of Safety Service indicator adds an extra dimension to the understanding of intersection safety performance. It provides a consistent and straightforward method for national, regional and local Road Controlling Authorities to assess their intersections against comparable intersections from around New Zealand. The approach incorporates historic crash data, intersection configuration and control, the speed environment, and traffic flows.

This approach highlights intersections that perform poorly compared to similar intersections, even if their total or per-vehicle crash rate is not high enough to make them stand out. These intersections often have inherent flaws that make them more dangerous than usual, and can be readily mitigated. Intersections that perform better than most similar intersections, but that still have a high crash rate, are likely to require more extensive transformation to deliver safety improvements.

The Level of Safety Service technique has been used to inform intersection intervention prioritisation studies in Auckland, Hastings, Wellington and Christchurch, and with the upcoming publication of the final version of the High Risk Intersections Guide will be available to all practitioners to help produce a safer transportation system.

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