# Traffic Safety Effects of Advanced Warning Flashing Lights at Intersections on High-Speed Roads, Perth Metropolitan Area

**Tony Radalj[1] (Presenter)**
**[1]Main Roads Western Australia**

**Biography**

Tony joined Main Roads Western Australia in 1988 as a Research Officer to work on database systems projects related to traffic, road and road use information.

He currently holds the position of Road Safety Analyst with the organisation working on a number of road safety, traffic and road engineering research projects, including evaluation of 50 km/h speed limit on residential streets in the state. He has produced a number of reports in areas of traffic and road safety in Western Australia. He is a member of a number of road safety committees and task forces in the state.

**Abstract**

A study was undertaken to evaluate effects of Advanced Warning Flashing Lights (AWFLs) at a sample of 25 intersections on Perth metropolitan highways having open road section speed limits ranging from 70 to 100 km/h. The lights had been installed over the period between 1993 and 2000. The study methodology was based on a "before/after" design by comparing the crash frequency and costs of crashes before and after installation of the AWFLs, over equal length time periods. The estimates of the effects were based on the crash data collected over 62.94 years of operations at the sample of intersections.

The study showed that there was a reduction of 5 fatal crashes after the installation of the lights at the affected 400 m approach road sections including the intersections. The AWFLs were found to be associated with significant change in types of crashes such that more severe crashes were reduced and less severe crashes increased. The expected changes were as follows: 22% reduction in right turn against crashes, 17% reduction in right angle crashes, 12% increase in rear end crashes, 11% reduction in side-swipe crashes, and 14% increase in other types of crashes. The overall increase in all types of crashes was estimated at 3%, well below expected of 6%. A multivariate analysis indicated that the "after" period is characterised by: fewer fatal crashes, fewer right turn against and right angle crashes, more rear end crashes, more crashes on 100 km/h roads than on <=90 km/h roads, and more crashes at road sections than at intersections.

Estimates of effects of AWFLs in terms of cost of crashes suggested that the reduction in the costs was in the range between $14,000 and $139,000 per intersection per annum. It is estimated that AWFLs may reduce cost of crashes by up to 22%. It was estimated that AWFLs were at least three times more effective in reducing cost of crashes involving heavy vehicles than the cost of crashes involving other types of vehicles.

## 1. INTRODUCTION

In an effort to address the issue of traffic safety at signalised intersections, Main Roads Western Australia has undertaken a program of installation of Advanced Warning Flashing Lights (AWFLs) at the approaches to signalised intersections on high speed roads, in particular those forming part of the heavy vehicle routes network within the metropolitan area. Since its inception in 1989, by the year 2000 the program has grown to over thirty sites, including a few of the installation in regional centres. Most of the AWFLs installations have been done within the last nine years. The AWFLs were generally installed on roads where the posted speed limit was 80 or more km/h.

Despite relatively small percentage of fatal crashes in the metropolitan area occurring at signalised intersection (on average 8.5 crashes, 9.7% for the period 1985 to 2000), there is a high level of public concern for traffic safety at intersections on high speeds roads, especially where the roads serve as heavy vehicle routes. Intersections on high speed roads (70 km/h or higher) on which AWFLs are mainly installed account, for less than 2% of all fatal crashes within the area. However, more than 21% of all fatal crashes at signalised intersections occurred at the intersections located on these types of roads. Crashes occurring on high speed road intersections are more likely to result in more severe outcomes than the crashes occurring on lower speed road intersections. The statistics for the 1985-2000 period suggests that crashes that occur on high speed road intersections (7% of all crashes at signalised intersections) result in significantly larger proportion of fatal (0.40%) and serious injury crashes (4.46%) when compared to the lower speeds road intersections resulting in 0.11% fatal and 3.22% of serious injury crashes.

Five percent of heavy vehicle crashes in the Perth metropolitan area account for 11.4% of all fatal crashes in the area, of which 20% occur at signalised intersections (7.8% at the high speed road intersections and 12.2 at the lower speed intersections). It is estimated that approximately 5.5% of crashes involving heavy vehicles at signalised intersections account for 24.3% of all fatal crashes occurring on these locations. Crashes involving heavy vehicles at the high-speed road intersections are 1.7 times more likely to result in a serious injury crash than the crashes at the low speed road intersections

Although a substantial number of intersections have been treated with the AWFLs, very little evaluation has been done on their effectiveness, especially on reduction or increase in various types or severity of crashes. Few studies have investigated AWFLs safety benefits in terms of: reduction in number of crashes, change in patterns of types of crashes, severity of crashes or cost of crashes.
The purpose of this study is to carry out an evaluation of the effects of AWFLs on a sample of intersections and sections of roads based on all reported crashes, including heavy vehicle crashes, before and after the installation of the lights.

Previous research (Gibby et al. 1992) found that high-speed approaches with AWFLs had significantly less total, right angle and rear end crashes when compared to similar sites without AWFLs. Similarly, Sayed et al. (1999) found that intersections equipped with AWFLs had a lower frequency of crashes than similar locations without AWFLs. Klugman et al. (1992) found that higher percentage of red light violations occurred at sites without the AWFLs than at sites with the lights. Contrary to some of the research findings, this study showed no consistency in the effects of AWFLs, such that the effects varied between two districts, where crash frequency of the same types of crashes decreased in one but increased in the other. Despite inconsistencies in literature with respect to safety benefits of AWFLs, they seem to be recognised by drivers as one of the beneficial road safety treatments on high-speed roads.

## 2. METHODOLOGY

Due to a relatively small number of intersections with AWFLs in Western Australia, the entire population of thirty two intersections was considered in the study with the year of installation ranging from 1989 to 2000. The choice of the design of the study together with constraints related to installation dates coinciding with installation dates of traffic signals and availability of crash data resulted in a sample significantly less than the current population.

A simple before-after study design has been utilised to assess effects of AWFLs . Up to three years of “before” crash information is compared against the same length “after” period for each of the sites across the whole study sample. The effects are measured in terms of change in: total number of all crashes, types of crashes, severity of crashes, crashes involving heavy vehicles (AUSTROADS Classes >= 3) and cost of crashes. Changes in these indices were investigated for the intersections and road sections 200 m each side from the intersections. The crash data covered up to 3-year period for each of the intersections and 400 m sections of the roads equipped with AWFLs. The data was then broken down by crash types into five groups: right turn against, right angle, rear end, side-swipe same direction and all other types of crashes. Similarly, in terms of severity, crashes were grouped into four categories: fatal, serious injury, medical treatment and property damage only (PDO) crashes. Estimated differences in types, severity and cost of crashes between “after” and “before” periods were used to assess effects of AWFLs at the 400 m road sections.

Although road safety literature suggests that a 3-year period is a quite acceptable comparison period for before-after studies, a control sample of similar intersections and sections of roads were chosen to make adjustments for the changes in number and types of crashes expected over the three year period after installation of AWFLs due to factors not controlled in this study, such as traffic exposure, enforcement, or public traffic safety education.

The study sample consisted of 25 intersections chosen from the population of thirty two sites. An investigation of the crash data trends for the period 1992 to 2000 indicated that there was a fairly linear increase in all type of crashes over the period so that this relationship between the years and number of reported crashes could be used for adjustment purposes in order to estimate number of expected crashes in the “after” period by applying linear regression parameter estimates.

The sample of intersections equipped with AWFLs were located on the metropolitan highways with open road sections speed limits ranging from 70 km/h to 100 km/h, of which 11 road sections had 100 km/h speed limits, 2 sections 90 km/h, 7 sections 80 km/h and 5 sections 70 km/h. Each of the open road sections speed limits are normally reduced by 10 or 20 km/h at the intersection approaches. Under an assumption that number of crashes, types of crashes and severity of crashes may be related to speed differentials, the sample was divided into two speed limit groups defined as: high speed (100 km/h) and low speed sites (<= 90 km/h).

## 3. ANALYSIS

The sample crash data observation periods varied between the sites, ranging from 104 days to the maximum of 3 years, depending on the dates of traffic lights and AWFLs installations, and availability of crash data over the same length of time for each of the sites in the sample. Mean duration for each of the observation periods, “before” and “after”, was 2.52 years, resulting in 62.94 years of crash data during AWFLs operation across the sample that could be compared against the data observed over same period of time before their installations. The effects of AWFLs measured in terms of change in number of crashes, types of crashes and cost of crashes are estimated for the following locations: intersections, road sections within 200 m each side from the intersections, and the total 400 m affected length of road.

### 3.1 Frequency and Costs of Crashes at Intersections Before and After Installation of AWFLs

Overall, the “after” period recorded 68 crashes more than the “before” period. The data suggests that there were no differences in the distribution of crashes with respect to crash severity, however, some significant changes were observed in types of crashes as proportions of the total crashes at the intersections ($\chi^2 = 16.41$, $p < 0.01$). The changes are largely associated with the increase in rear end crashes (7.3%), and to a lesser extent with the decrease in right turn against (3.8%) and right angle crashes (2.3%). In terms of change in absolute number of crashes within the crash types, the greatest change was observed on rear end crashes recording an increase of 126 crashes during the “after” period compared to the “before” period, corresponding to the increase of approximately 19%. The increase in the rear end crashes is offset by the decrease in right turn against, right angle and side-swipe crashes, 34, 21 and 11 crashes, respectively, representing the decrease of 21% for right turn against and right angle crashes, and 14% for side-swipe crashes. A relatively small increase of 9% was observed in other types of crashes (see Figures 1). No significant changes in the distributions of crash severities were observed across the crash types. Although not statistically significant, the number of fatal crashes reduced by 50%, from 4 crashes to 2 crashes, associated with right turn against types of crashes. The total number of crashes increased by 6%.

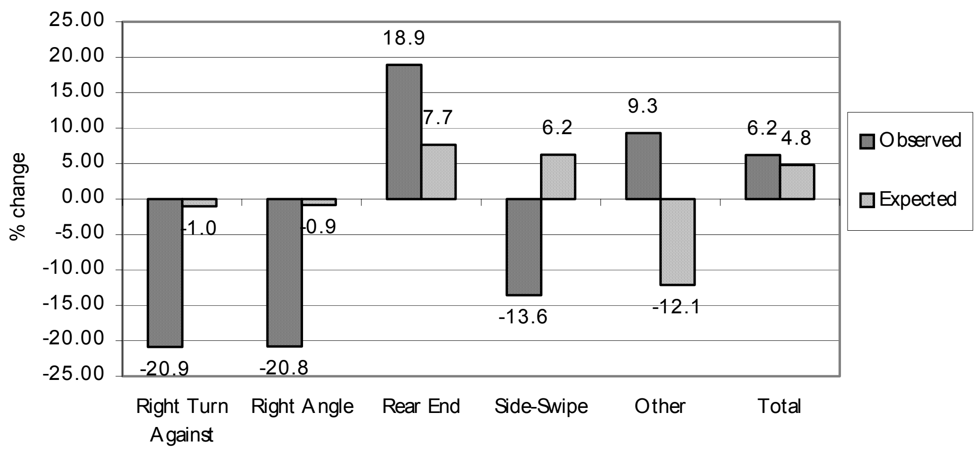


**Figure 1.** Observed and expected percentage change in types of crashes after installation of AWFLs at the intersections

Examination of the crash type trends at the sample of control intersections indicated that there
was a linear relationship between the time and number of crashes, $R^2$ ranging from 0.02 for right angle crashes to 0.90 for rear end crashes. Some types of crashes increased over the time while the others decreased. The average changes in types of crashes varied from the decrease of 10.8% in other types of crashes to the increase of 8.3% in rear end crashes. The decrease in right turn against and right angle crashes was insignificant, approximately 1%.
After an adjustment for the trends in the control sample, it was estimated that the 20% reduction in right turn against and right angle crashes could be attributed to the effects of AWFLs at the sample of intersections. The observed increase in rear end crashes of 19% after the adjustment is reduced to the increase of approximately 10%. Quite significant reduction in side-swipe crashes of 19% and the increase of 22% in other type of crashes were attributed to the existence of AWFLs at the intersections. Overall, in terms of the total number of crashes, it is estimated that the effect of AWFLs was negligible, being associated with the increase of only 1%, compared to the observed increase of 6% during the “after” period.

The analysis suggests that AWFLs have no significant effects on the total number of crashes. However, it appears that the presence of the lights at the approaches to signalised intersections have a significant effect on types of crashes that occur at these locations, resulting in a shift from more severe (right turn and right angle crashes) to less severe types such as rear end crashes. This change in pattern of types of crashes may be associated with a satisfactory decrease in cost of crashes resulting in the cost/benefit ratio significantly greater than 1.

In attempt to estimate cost of crashes two approaches were considered: (i) cost based on observed severity of crashes, and (ii) cost based on average crash type costs for the intersections over the “before” and “after” periods. It was considered that the effects of AWFLs purely based on the observed crash frequencies might be biased towards higher than expected effects due to possible random occurrence of more severe types of crashes, such as fatal crashes while crash costs based on the average crash type costs might give better estimates of the minimum crash cost difference between the periods. In order to assess effects of AWFLs in terms of costs based on crash severity costs and observed frequencies, the following costs were used in the estimates: fatal crash, $1,810,874; serious injury, $306,472; medical treatment, $15,961; and PDO, $10,202. Based on these crash costs, the overall cost reduction during the “after” period amounted to the average annual crash cost reduction of $48,980 per intersection, compared to the annual reduction of $21,000 based on crash type costs (right turn against, $56404; right angle, $61089; rear end, $13064; side-swipe, $12622; other, $43921).

An adjusted annual crash cost reduction based on the expected number of crashes attributable to AWFLs was slightly larger at $25,000 per intersection. It can be said that crash type based estimates are fairly conservative in that they may represent the minimum expected benefits to be achieved by equipping an intersection with AWFLs on similar traffic and road environments.

### 3.2 Frequency and Cost of Crashes at Sections of Roads

For simplicity of crash data analysis and assumed driver reactions to the AWFLs through modified behaviours according to some form of subjective assessment of downstream traffic and road environment conditions, 200 m before and 200 m after the intersections, excluding the intersections, were considered for assessment of effects of the lights by comparing type and severity of crashes before and after installation of the lights.

Some reductions in higher severity groups were observed during the “after” period, 3 fatal and 3 serious injury crashes. After an adjustment for the crash type trends at the control 400 m sections of roads, excluding the intersections, a significant increase was observed in rear end type of crashes, approximately 31%. It was estimated that AWFLs attributed to the increase of 15% in the total number of crashes.

The annual reduction in cost of crashes at the 400 m sections of roads between the “after” and “before” periods amounted to $90,000 per site, mainly accounted for by the decrease in fatal crashes. However, an application of the more conservative average crash type cost for the sections of roads to the difference in number of crashes resulted in the increase in cost of crashes after installation of the AWFLs to the amount of $7,600 per intersection per year.

### 3.3 Frequency and Cost of All Crashes within AWFLs Affected Area

Comparison between the two periods in the total number and types of crashes suggested that the “after” period experienced 113 more crashes than the “before” period, 1377 vs. 1264. In addition, there were significant differences in the proportion of crash types between the periods ($\chi^2$ = 18.94, d.f. = 4, $p < 0.001$), attributed to a reduction in right turn against (from 13.4% to 9.5%) and right angle crashes (from 8.7% to 6.8%), and an increase in rear end crashes (from 59.4% to 66.7). Although there was a noticeable reduction in more serious injury crashes during the “after” period, especially fatal crashes, from 7 to 2, no statistically significant differences were shown in the distribution of proportions of the crash severities.

Adjustment for the trends in types of crashes at the control sections/intersections with the expected annual rates, as presented in Table 1, suggests that installation of AWFLs attributed to the changes in proportions of crash types as follows: 22% reduction in right turn against crashes, 18% reduction in right angle crashes, 13% increase in rear end crashes, 12% reduction in side-swipe crashes, and 13% increase in other types of crashes.

| Crash Type | Crash Severity | | | | | | | | | | Total % Change | | % Att. to AWFLs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Before | | | | | After-Before | | | | | | | |
| | Fat. | Ser. Inj. | Med. Treat. | PDO | Total | Fat. | Ser. Inj. | Med. Treat. | PDO | Total | Obs. | Exp. | |
| Right Turn Against | 2 | 14 | 42 | 112 | 170 | -2 | 4 | -12 | -29 | -39 | -22.94 | -0.73 | -22.21 |
| Right Angle | 1 | 12 | 28 | 69 | 110 | 0 | -5 | -6 | -6 | -17 | -15.45 | 2.38 | -17.84 |
| Rear End | 0 | 7 | 150 | 594 | 751 | 0 | 0 | 67 | 101 | 168 | 22.37 | 8.89 | 13.48 |
| Side-Swipe | 0 | 1 | 12 | 97 | 110 | 0 | 0 | -3 | -3 | -6 | -5.45 | 6.34 | -11.80 |
| Other | 4 | 9 | 13 | 97 | 123 | -3 | -3 | 3 | 10 | 7 | 5.69 | -7.76 | 13.45 |
| All | 7 | 43 | 245 | 969 | 1264 | -5 | -4 | 49 | 73 | 113 | 8.94 | 5.76 | 3.18 |

**Table 1.** Differences in number of crashes after and before installation of AWFLs at the affected 400 m road sections including intersections

It seems that AWFLs have a substantial effect on reduction in more severe types of crashes, but in the same time are associated with an increase in less severe types of crashes such as rear end crashes. The lights seemed to be associated with an increase in the total number of crashes, estimated at 3%.

Comparison of costs of crashes, based on severity of crashes, between the “after” and “before” periods showed a significant reduction in the cost of right turn against, right angle and other types of crashes (see Table 2). Although there was a slight increase in number of other types of crashes during the “after” period, these types of crashes resulted in the largest crash cost reduction to the amount of $6 million. The cost reduction was mainly associated with the reduction of 3 fatal crashes, from 4 before to 1 after installation of AWFLs. The overall reduction in cost of crashes during the “after” period was estimated at $8.75 million, equating to the average of $139,000 per year of operation per intersection. A more conservative approach for estimation of the costs was examined utilising average crash type costs over the two periods. Application of the average crash type costs on the estimated number of crash types attributed to AWFLs resulted in the total reduction in cost of crashes of $0.9 million over the average 2.5 years of AWFLs operation per intersection in the sample. Average crash cost benefit per intersection per year was estimated at $14,000.

| Crash Type | Diff. in Cost Based on Observed Crash Severity ($M) | Annual Average Cost Diff. ($1000)/ Inter. with AWFL | Average Cost by Crash Type (Bef./After) | Est. No. of Crashes Attribut. to AWFL | Change in Cost Attributed to AWFL ($M) | Annual Average Cost Diff. ($1000)/Int. with AWFL |
|---|---|---|---|---|---|---|
| Right Turn Against | -2.88 | -45.81 | 55041 | -38 | -2.08 | -33.02 |
| Right Angle | -1.69 | -26.84 | 57091 | -20 | -1.12 | -17.80 |
| Rear End | 2.10 | 33.36 | 13951 | 101 | 1.41 | 22.44 |
| Side-Swipe | -0.08 | -1.25 | 13536 | -13 | -0.18 | -2.79 |
| Other | -6.20 | -98.55 | 64014 | 17 | 1.06 | 16.83 |
| All | ***-8.75*** | ***-139.08*** | | 40 | ***-0.90*** | ***-14.34*** |

**Table 2.** Estimates of cost of crashes for the 400 m sections of roads

Estimates of effects of AWFLs in terms of costs of crashes based on the average crash type costs approach are likely to underestimate the true crash cost benefits resulting from installations of the lights. Therefore, crash cost reduction during the “after” period is expected to be between the two estimates, $14,000 and $139,000 per year per intersection, a reduction in the cost ranging from 2% to 22%.

### 3.4 Crashes Involving Heavy Vehicles at the 400 m Sections of Roads

The "after" period experienced 1 fatal crash compared against 3 fatal crashes during the "before" period. After an adjustment for the trends in heavy vehicle crashes it was estimated that the AWFLs attributed to the overall increase of 12 (8%) heavy vehicle crashes. However, more significant differences attributable to the lights were found between crash types such as: 32% reduction in right angle crashes, 55% increase in rear end crashes, and 46% reduction in other types of crashes.

Based on the observed crash severity frequencies, the annual cost reduction of crashes involving heavy vehicles after installation of AWFLs was estimated at $49,500 per intersection. A more conservative estimate of the crash cost reduction, adjusted for trends in the heavy vehicle crashes, amounted $16,800. Comparison between the observed reduction in cost of heavy vehicle crashes and the reduction in cost of all vehicle crashes suggests that the heavy vehicle crashes (12% of all crashes) accounted for 36% of the total cost reduction. The observed and estimated reductions in cost of crashes involving heavy vehicles and those not involving these vehicles suggest that *AWFLs are at least three times more effective in reducing cost of crashes involving heavy vehicles than the cost involving other types of vehicles*. This is not related to the reduction in number of crashes but to the change in patterns of types and severity of crashes.

### 3.5 Association between Types of Crashes, Severity, Location, Speed Limit and "Before/After" Periods

A multivariate log-linear analysis indicated that there were significant differences in the distributions of types of crashes between the locations over the observation periods such that intersections recorded more rear end crashes than the sections of roads (64% vs. 56%) while the sections experienced more side-swipe crashes than intersections (16% vs. 7%). Similarly, rear end crashes were more likely to occur on the higher speed roads than the lower speed roads (66% vs.59%), while more side-swipe crashes were expected on the lower speed roads than on the higher speed roads (9% vs. 7%).
Controlling for other factors in the model, there seems to be significant association between location and severity of crashes. Although, over the periods, six fatal crashes occurred at the intersections, compared to 3 fatal crashes at the road sections, a crash is more likely to result in a fatality at the sections rather than at the intersections (0.79 vs. 0.27%). Assuming that all factors remained the same of the two observation periods, "before" and "after", from the distribution of crashes over the periods, it can be inferred that AWFLs had a significant effect on the increase in rear end crashes ( 59.4% to 66.7%), decrease in right turn against (from 13.4% to 9.5%) and right angle crashes (from 8.7 to 6.7%).

Further application of multivariate analysis using discriminant analysis indicated that "after" and "before" periods discriminated on: speed limit, fatal crashes, right turn against, right angle, rear end crashes, and to some extent on location of crashes (Std D = -0.350Speed Limit +0.315Loc + 0.300Fat + 0.453RTA + 0.275RA - 0.308RE, Wilks' Lambda=0.99, F=3.2, d.f.=9, $p < 0.001$). The "after" period seemed to be characterized by less number of fatal crashes (OR=0.30), less number of right turn against (OR=0.74) and right angle crashes (OR=0.81), more rear end crashes (OR=1.14) and more crashes on 100 km/h than on <=90 km/h roads (OR=1.16), and quite likely more crashes at road sections than at intersections (OR=1.21).

## 4. SUMMARY AND CONCLUSIONS

The study examined effects of the AWFLs over the selected length of road defined as the section within 200 m from and including the intersections. Comparison of number, types and severity of crashes between the two periods, before and after installation of AWFLs, at the 400 m sections of roads, suggests that the lights have a substantial effect on driver behaviours resulting in less severe than expected outcomes within the similar environments not equipped with such devices. This study showed that there was a reduction of 5 fatal crashes after installation of the lights, 7 crashes before compared against 2 crashes after. However, a noticeable increase in crashes requiring medical treatment was recorded during the "after" period. The study suggests that AWFLs are associated with significant change in types of crashes expected at the affected road sections such that more severe types of crashes are reduced and less severe crashes increased.

The results obtained in this study are generally consistent with results from previous investigations found in the literature. The crash data analysis for the sample suggests that AWFLs over affected area of the 400 m sections of roads, including intersections, account for:
22% reduction in right turn against crashes, 17% reduction in right angle crashes, 12% increase in rear end crashes, 11% reduction in side-swipe crashes, 14% increase in other types of crashes, and overall increase in all types of crashes of 3%.

Estimates of effects of AWFLs in terms of cost of crashes suggested that the annual reduction in the costs could be between $14,000 and $139,000 per intersection. Assuming that all factors remain the same, over sufficiently long period of time, it is expected that AWFLs would reduce cost of crashes up to 22% when compared to the cost of crashes over the same length of time before their implementation.
The comparison between the total number of crashes before and after installation of AWFLs indicates that their effects are higher at the lower than at the higher speed limit sections of 100 km/h. Over the affected area, the 100 km/h roads recorded an increase of 115 crashes (17%) compared against a negligible decrease of 2 crashes at the lower speed roads.
Over the observation periods, 12% of crashes involved heavy vehicles, accounting for 44% of all fatal crashes, 3 crashes before and 1 crash after the installations of AWFLs. AWFLs attributed to the increase of 8% in heavy vehicle crashes. However, the cost of crashes during the "after" period was reduced between $17,000 and $49,000 per year per intersection. A comparison between the reduction in cost of heavy vehicle crashes and the reduction in cost of all vehicle crashes suggests that effects of AWFLs are three times greater on heavy vehicles than other vehicle types, considering that 12% of the crashes involving heavy vehicles account for 36% of the cost of all crashes.

This study showed that AWFLs have positive effects on reduction in number and cost of crashes within the range of 400 m of road sections including. Although there might be differences in effects at different points along the approaches or at the intersections, the overall benefits of the lights cannot be negated.

## 5. RECOMMENDATIONS

It is recommended that the findings of this study should be used as a basis for future expansion of the AWFLs program within the metropolitan area and regional centres. It is worth to note that application of AWFLs should not be constrained only to high speed roads but to other speed limit environments for which safety warrants exist. The study suggests that their effectiveness is even greater at the roads with speed limits less than 100 km/h such as the speed limits ranging from 70 to 90 km/h.

The factors derived in this study on effects of AWFLs on number, types and severity of crashes may be used for establishing "safety warrants" based on cost/benefit ratios when considering installation of the lights at various intersection/road section configurations. It is recommended that the factors be used for estimation of expected changes in number and types of crashes over period of time from which cost/benefit analyses can be performed.

It is recommended that further investigations be undertaken to look into the reasons for the differences in the effects of AWFLs between speed limits, and the differences between road sections and intersections, possibly associated with distance of the lights from the intersections, timing of the lights, or some other factors not investigated in this study.

**References**

Gibby, A.R., Washington, S.P., and Ferrara, T.C. Evaluation of High-Speed Signalized Intersections in California. In *Transportation Research Record 1376*, TRB, National Research Council, Washington, D.C., 1992, pp. 45-56.

Klugman, A., and Belrose, M. *A study of the Use and Operation of Advanced Warning Flashers at Signalized Intersections*. Report MN/RC-93/01. Minnesota Department of Transportation, Saint Paul, Minn., 1992.

Sayed, T., Vahidi, H., and Rodriguez, F. Advance Warning Flashers Do They Improve Safety?. In *Transportation Research Records 169,* TRB, National Research Council, Washington, D.C., 1999 , pp. 30-38.

**Keywords**

AWFLs, intersection, crash types, cost of crashes