COMPARATIVE ANALYSIS OF ACCIDENT POTENTIAL OF PRIORITY JUNCTIONS WITH DIFFERENT LAYOUTS AND CONTROLS

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ABSTRACT

Techniques for evaluating the accident potential of junctions are mostly based on 'before and after' comparisons of accident experience following the implementation of specific measures. In this study, a simple procedure is adopted where priority junctions characterized by some key features are compared on their accident potential, represented by accident frequency, accident rate and casualty rate. It was expected that the results from such a study would have broader application than those from the traditional 'before and after' study. A case study of 91 urban priority junctions, comprising 57 T-junctions and 34 X-junctions was designed. The T-junctions were of six generic types, whilst X-junctions consisted of three types. Generally, junctions without any form of channelisation or divisional island on one or more of the approaches had accident potential between 1.5 to 2.5 times that of comparable junctions with these features. At junctions with dual-carriageway arterial roads, the presence of a dedicated left-turn storage lane appeared to enhance both safety and capacity. Significantly, stop-controlled junctions were statistically unsafer than those with yield or no control. The minor road's share of traffic appeared also to be significantly associated with accident potential. From a safety perspective, the results show that a critical situation arises when the minor road's share of traffic approaches 25-27% and 29-30% respectively for T-junctions and X-junctions respectively. At these thresholds it is recommended that serious consideration be given to upgrading the priority status of junction control.

Keywords: Urban priority junctions, junction control, accident potential, minor road traffic, Ghana

1. INTRODUCTION

1.1 Significance of junctions and junction control

Junctions, as an integral part of every road network, provide a crucial framework for resolving conflicts between opposing traffic streams. This enables motorists to change direction of travel in order to get to their desired destinations. To ensure that this function is performed efficiently, a variety of means is usually employed, ranging from simple road-line markings and signs, through channelisation with ghost islands or physical demarcation, to the use of traffic signals. It would appear that the main criterion for preferring one type of control to another is often the desire to minimise delay and increase capacity (TRL, 1991; MUTCD, 1978; HCM, 1997). Although safety considerations do play a role (ITE, 1982), the analytical basis of safety warrants has been strongly criticised by a number of researchers as being "shaky" (e.g. Persaud, 1988; and Hauer *et al.*, 1989).

For the broad group of unsignalised (non-signal-controlled) junctions, however, the choice is often between different levels of priority control. This group usually constitutes the preponderant majority of junctions, probably due to their simplicity and relatively cheap costs of installation and maintenance. Because priority junction controls are usually not self-enforcing, however, the potential for inter-vehicular conflict and accidents at such junctions is relatively high, especially in conditions where driving quality, as manifests in lane discipline and observance of traffic regulations, can at best be described as suspect (Salifu, 1998).

Notwithstanding the important role unsignalised junctions play in traffic management, and the fact that they currently account for about 70 per cent of all accidents at urban junctions in Ghana, little to date is known about their accident potential relative to other types of junction. Also, little or no information exists about the accident potential of the many different types of priority-controlled junctions or their relative safety performance. The absence of such information is clearly a significant handicap in the safe and efficient management of traffic in urban areas.

1.2 Objective and scope of study

The main objective of this study is to provide general guidance on the key attributes and features of priority-controlled junctions that enhance safety. A comparative analysis of the accident potential of selected priority junctions characterized by identified features shall be carried out on the basis of which such guidance shall be provided. The study is based on a case study of priority junctions in urban areas of Ghana.

2. REVIEW OF PREVIOUS STUDIES

The relevant literature on the subject of safety at junctions have been mostly presented in the form of "before and after" studies. Studies of this nature generally deal with the comparison of safety levels during equivalent periods before and after the implementation of specific road measures. Hauer and Lovell (1986) believe that this method of safety evaluation is the method of choice, provided that comparisons are done properly because, in their opinion, the safety effects of various measures are better extracted from real-life implementations than from experiments that are staged to meet the dicta of rigorous scientific design. They contend that the implementation of a real measure, such as safety interventions, is usually fashioned by the circumstances of the real world and only seldom by the requirements of scientific experimental design.

Polus (1985) investigated the associated changes in accident rates when "STOP" signs were interchanged with "YIELD" signs at selected unsignalised urban intersections because of their accident history. He reported that the increase in the level of control at such junctions through replacing "YIELD" with "STOP" signs tended to increase vehicle accidents but reduced pedestrian accidents. On the whole, therefore, he concluded that increasing the level of control at unsignalised junctions would not necessarily result in an overall reduction in accidents, although it might reduce, on average, the severity of injuries. Other studies, for example, Lum and Parker (1982), Chadda and Parker (1983), Upchurch (1983), Lum and Stockton (1982), and David and Norman (1975), generally agreed with the conclusions of Polus (1985) and went on to decry the "over-use" of "STOP" signs or four-way control, as being merely restrictive and not justified by the operational and environmental impacts resulting from their use.

After reviewing a number of studies on the conversion of two-way to four-way controls, however, Lovell and Hauer (1986) did not subscribe to the view that such conversions were merely restrictive and did not deliver the desired returns in safety. They contended that some of the results that supported the latter position had been influenced to some extent by elements of the regression-to-mean phenomenon.

King and Goldblatt (1986) investigated the change in accident patterns accompanying signalization of priority junctions. Using analysis of variance and regression techniques, they observed that whilst there was a definite shift in the distribution of accident-types, there appeared to be no clear-cut evidence that the installation of signals had reduced accidents overall. On the contrary, they noted, in some cases, signalised intersections actually had higher accident rates. Frith and Harte (1986) and Frith and Dery (1987), however, were less equivocal after carrying out similar studies. Whereas the former observed that "in appropriate situations, all control-changes offer considerable safety benefits", the latter urged caution in assuming that signalising an intersection will automatically lead to an aggravation of its underlying accident problem.

Other researchers have discussed changes in safety from the perspective of warranted and unwarranted changes in traffic control. For example, Hanna *et al* (1976) compared the safety performance of warranted and unwarranted signal installations on rural roads and found similar accident rates for both types of installation. In other words, whether the signals were installed at locations meeting the requirements for upgrading priority control to signals or not, the resultant effect on accident numbers was the same. On the other hand, Hakkert and Mahalel (1978) and King and Goldblatt (1975), from studies of urban intersections, reported a tendency for accident rates to increase with signalisation, especially at intersections not meeting the volume or accident warrants.

Persaud (1986) also reviewed a number of studies that investigated the effect of increasing the level of junction control through conversion from two-way to multi-way stop control. He reported that the measure appeared more effective when implemented on intersecting roads, where the traffic volumes were nearly equal and the total of these volumes between 6,000 and 12,000 vehicles per day. This seemed to agree, generally, with the provisions of the Manual on Uniform Traffic Control Devices (MUTCD, 1978). The Manual stipulates that multi-way (4-way) stop control is warranted where *"the volume of traffic on the intersecting roads is approximately equal"* and *"the total vehicular volume entering the intersection from all approaches averages at least 500 vehicles per hour for any 8 hours of an average day"*.

In a further comment, however, Persaud (1988) also reports that there is no credible evidence to suggest that stepping up the level of control at a junction is effective in reducing accidents only for certain ranges of total entering traffic volumes. Neither is it apparent, in his opinion, that the safety effectiveness of such a change in control depends on how this volume is split among the approaches. On the contrary, he concludes that in the particular case of conversion of two-way to multi-way stop control, the safety effectiveness of the measure (i.e. percent reduction in accidents) is higher only at sites with greater numbers of expected accidents.

The apparent implication is that there is no obvious relationship between the expected number of accidents at a site, i.e. the site's accident potential, and the total traffic inflows or the relative split of the flows among the junction approaches. That is intriguing, because junction throughput and the share of minor road traffic are generally seen as indices of exposure of traffic to the risk of accident and if these are said not to have any influence on accident numbers, then it leaves one with some confounding questions. First of all, what then will constitute an appropriate exposure index and, secondly, is one to believe, as Persaud's (1988) conclusions appear to imply, that traffic accidents could arise out of zero traffic flows? In an attempt to escape these difficult questions, the author suggests that *"there could be other exposure measures which could have an influence"*, although he does not immediately suggest any alternative.

Hauer *et al* (1989) also cast doubt on the credibility of traffic control warrants as safety interventions, as well as on studies that appear to lend uncritical credence to them. The authors are of the view that the analytical basis in either case is faulty and tends to lead to exaggerated conclusions about the effectiveness of traffic control measures. One of the key criticisms of such studies is that they were based on comparisons of "before" and "after" accident counts, when instead they ought to be comparing "before" accidents with expected accidents, assuming that the measure had not been implemented.

Despite the lack of consistency, the above findings have some potentially interesting implications for traffic management and safety overall. The very rationale and appropriateness of safety warrants, as recommended in various manuals (i.e. MUTCD, 1978; DOT (USA), 1981 and Highway Capacity Manual, 1997) has been questioned, since, as a rule, these manuals will recommend higher levels of control at sites with high accident rates. As a result, it is has often been taken for granted that increasing the level of control at junctions, through signalisation for example, is an effective remedy for unsignalised sites with bad accident records. But, as the above results would show, the issues are probably, not as clear-cut as that.

In practical terms, what the findings mean is that, if only on account of their safety performance, priority junctions could be maintained to cater for some levels of traffic currently deemed manageable only by signals. In the process, by delaying the introduction of signals, or other "higher order" type of control, the extra resources that would otherwise be required could be utilised for more effective safety interventions elsewhere in the network.

Also, reducing the incidence of restrictive controls, which are not justified on account of the accident savings in particular, is likely to increase their effectiveness and the respect for them by drivers at other places where they are warranted. Such developments should have an overall positive impact on network-wide safety levels. But clearly, more information is required, particularly with regard to what could be the acceptable threshold limits and conditions for extending the deployment of non-signalised junctions for traffic management, essentially from a safety perspective.

What the current study seeks to do is to explore the relative safety performance of priority junctions of various control and layout combinations with a view to providing safety-driven guidance on their use. It is not a "before and after" study, in which case the findings might be constrained by the site-specific context of the evaluation. On the contrary, it is a cross-sectional study in which the accident potential of selected junctions defined by some key features are compared to enable broader inferences to be drawn.

3. DATA COLLECTION

The original database for this study was collected as part of a project for the development and application of accident prediction models for priority junctions in Ghana. Details of the methodology adopted can therefore be verified from Salifu (2002). The highlights are presented below:

In accordance with the rigorous requirements of the modeling database, the data collection process involved the selection of case-study junctions from the Kumasi and Accra Metropolitan Areas, the two most cosmopolitan cities in Ghana. Field data was then gathered at each of the junctions on traffic flows, including vehicle counts, classified by turning movements as well as the number of pedestrians crossing each arm of the junction, approach spot speeds of vehicles on the major arms and key geometric and site details of the junctions.

3.1 Selection of Case-Study Junctions

A judiciously selected sample of junctions, stratified mainly by traffic flow and junction features, was chosen to ensure that as wide a range of flows and junction features as possible would be captured. A purely random (and unstratified) sample of the same size, arguably, would not have guaranteed the inclusion of some key variables likely to have a significant impact on accidents.

An initial list of 130 junctions was compiled with the assistance of the respective maintenance engineers of the Department of Urban Roads (DUR), who had a good knowledge of the network conditions. Care was taken to have as wide a geographical spread as possible in order to include junctions with roads at different levels of the urban road hierarchy and with varying road and traffic conditions. All sites in this initial list were visited in a follow-up reconnaissance survey, during which some were discarded for various reasons, e.g. if the site had experienced any changes that could have affected its safety status in the period 1996-1998 for which accident data was retrieved for analysis, or if sight distances on the approaches were obstructed. The final sample was made up of 91 sites, comprising 57 T-junctions and 34 X-junctions. Six basic types of T-junction were captured. These are designated as T-1, T-2, T-3, T-4, T-5, T-6. X-junctions on the other hand were of three types; namely, X-1, X-2 and X-3. The typology of junctions is illustrated in Appendix 1.

3.2 Accident Data

Accident data, covering the period 1996-1998 inclusive, for both Accra and Kumasi Metropolitan Areas were retrieved from the national database at the Building and Road Research Institute (BRRI). This is a record of all accidents reported to the police and it represents the most comprehensive database on accidents in the country. The database is run on the Micro-computer Accident Analysis Package (MAAP5) developed by the Transport Research Laboratory of the United Kingdom (Hills *et al*, 1994). This is specialized software equipped with many diverse features for virtually any conceivable manipulation of accident data. Some of these features include cross-tabulations giving a general overview of the accident problem at any level, accident plots on scanned, or vector, maps to enable high accident locations to be easily identified and a very concise location-coding system that ensures that accidents occurring at specified locations on the road network can easily be retrieved.

Naturally, not all accidents will be reported to the police and this data is, therefore, subject to some shortfalls. However, since no extensive studies have been carried out to estimate the extent of under-reporting, it will be difficult to account for it in any systematic manner in the current study. Nonetheless it is assumed that the level of under-reporting is consistent, for which reason the data is assumed reasonably representative.

3.3 Traffic Flow Data

Traffic flow data gathered included vehicle counts classified by type of vehicle and turning movement, counts of pedestrians crossing all arms of the junction and spot speeds of vehicles as the vehicles approached the junction area along each of the major arms. For many of the sites, historical flow data for the study period were obtained from the Department of Urban Roads. Field surveys were conducted to collect the relevant data for the rest of the sites.

3.4 Site and Geometric Data

Junction inventories were carried out in both case study cities to collect or confirm information relating to the site details. The information collected included junction layout, type of major and minor roads (whether single or dual carriageway), numbers and widths of lanes, types of median, or other island, if any, and the dimensions. Other factors were types of traffic control, street lighting and pedestrian crossing facilities, whether designated or not. Due to the absence of as-built drawings for nearly all the sites, it was not possible to measure the radius of curvature of the entry kerb lines, which were considered important. Instead, as a good proxy for this, the widths of the minor roads were measured at the neck of the junctions in each case.

4. ANALYSIS OF ACCIDENT POTENTIAL OF THE CASE-STUDY JUNCTIONS

4.1 Accident Rates and Frequency

For the purpose of comparing the accident characteristics of the different types of priority junction, Table 1 provides summary information, such as the Average Annual Daily Traffic (AADT), the minor road's share of traffic and the accident frequency and rate for each junction type (see junction types in Appendix 1).

The lowest accident frequency (i.e. number of accidents recorded per year per site) for T-junctions is at junction type T-4 and the highest at type T-5.

T-4 represents an intersection between a 4-lane dual carriageway with kerbed medians on the main approaches and a standard 2-lane single-carriageway. Left-turning maneuvers are not possible at T-4 type junctions, because the kerbed median continues through the junction. T-5 is basically the same as T-4, except that at T-5 type junctions a break in the median allows left-turning maneuvers, i.e. equivalent to the right-turn in the UK.

For X-junctions, X-2 and X-3 had the highest and lowest accident frequencies respectively. Whereas the difference between the two extreme values of accident frequency was not statistically significant (*t*-test) for T-junctions, at X-junctions it was just significant at the 5 per cent level. As far as accident frequency is concerned, therefore, there is little to choose between the different types of T-junction. The apparent variation in values is most likely due to random factors. By contrast, however, it can be said that the typical X-3 junction has a significant tendency to record fewer accidents in any given year than any of the X-2 type. X-3 also records substantially fewer accidents than X-1. In statistical terms, the average T-junction also has about the same accident frequency as the corresponding X-junction. It needs to be noted, however, that accident frequency may not be the best indicator of safety at the different sites, since it does not take account of the intensity of use or the exposure to the risk of accident.

Probably, a relatively better basis for comparing the unsafety or accident potential of junctions is the accident rate, which is defined as the average number of accidents recorded per million vehicles using the given type of junction in the same time period.

Table 1. Traffic volume, accident frequency and rate by junction type

Junction type*	Number Of sites	AADT (vehicles/day)	Minor road's share of traffic (%)	Accident frequency (accidents/site/year)	Average number of accidents/year/ 10^6 vehicles entering the intersection
T-1	21	11,482 (1,386)	25.4 (2.3)	2.03 (0.49)	0.66 (0.19)
T-2	7	11,906 (1,724)	28.8 (3.3)	1.86 (0.59)	0.37 (0.11)
T-3	6	15,747 (3,176)	18.8 (5.9)	2.06 (0.57)	0.37 (0.11)
T-4	6	11,791 (1,262)	22.1 (8.3)	1.56 (0.92)	0.34 (0.16)
T-5	9	15,852 (2,297)	13.7 (3.4)	2.63 (1.02)	0.48 (0.13)
T-6	8	21,411 (2,973)	15.9 (3.5)	2.13 (0.61)	0.28 (0.09)
Average for T	-	**14,099 (1,969)**	**21.6 (3.8)**	**2.07 (0.66)**	**0.48 (0.14)**
X-1	14	11,764 (1,547)	35.6 (3.2)	2.33 (0.69)	0.54 (0.13)
X-2	11	18,901 (2,072)	16.0 (3.0)	3.03 (0.89)	0.48 (0.12)
X-3	9	18,386 (3,250)	33.0 (3.6)	1.48 (0.43)	0.22 (0.07)
Average for X	-	**15,826 (2,168)**	**28.6 (3.2)**	**2.33 (0.69)**	**0.44 (0.11)**

*See junction classification in Appendix 1; Note: Figures in brackets are standard errors of the mean values shown

In this regard, it can be seen that the trends are clearly different from that presented by accident frequency for the individual junction types, although overall accident rates also happen to be similar for T- and X-junctions.

T-1 has the worst accident rate (0.66 per million vehicles) and is considerably unsafer than T-2, T-3, T-4 and significantly more so than T-6. Although other factors may also be involved, this observation appears to underscore the safety benefits of using channelisation or carriageway dividers of some sort at junctions, the main features differentiating the rest of the T-junction types from T-1. The marked difference in accident rate between junction types T-5 and T-6 also shows that a separate storage lane for vehicles turning left from the major road could also improve the safety status of the junction.

In fact, T-6 is not only apparently much safer than T-5 and T-1 but, as the data shows, it also carries considerably more traffic and accommodates a higher proportion of minor road traffic than T-5 and almost double the traffic volume at T-1. T-6 type junctions, therefore, combine fairly well the twin attributes of lower potential for accidents and higher capacity, at least, within the limits of the range of traffic volumes and the splits between the major and minor arms of the junctions represented by the data. The difference in accident rate between junction types T-3 and T-5, notwithstanding the similar levels of traffic they handle, also probably gives a good account of channelisation on the minor road. This is consistent with what is generally expected, since the presence of kerbed islands on the minor road helps in organising turning movements of traffic and, by so doing, reduces conflicts and the chance of collisions at junctions.

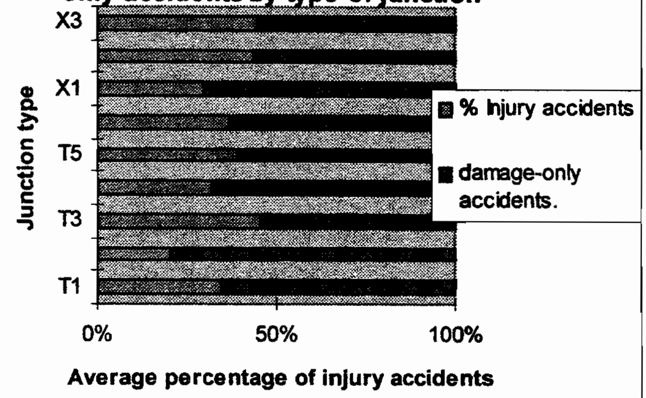
Accident rates of junction types X-1 and X-2 are significantly higher than that of X-3; each of the former having more than twice the accident rate of the latter. Whilst being the least accident-prone, type X-3 junctions also carry twice the minor road proportion of traffic as X-2 and one and a half times the overall traffic volume of X-1. This would again underscore the potential benefits of having storage lanes for left-turning traffic on the major road.

4.2 Severity of accidents

Accident severity here is presented as the average percentage of injury (i.e. fatal, severe and minor injury) accidents in relation to all accidents recorded at the different junction types. As is evident from Figure 1, among the T-junctions types T-2 and T-3 have the lowest (20.5) and the highest (46.0) percentages respectively, of accidents involving injury. The difference between these two proportions is significant at 95 per cent confidence level. Speed may be an important factor here, since more than 70 percent of average vehicle spot-speeds on the major approaches to T-3 type junctions are above 50km/h, as against only 15 per cent at junction type T-2 (see Salifu, 2002).

However, although the same percentage of spot-speeds

Figure 1. Balance of injury and damage-only accidents by type of junction



above 50km/h are recorded at T-3 junctions as at T-4, the latter still have significantly (at 5% level) less injury accidents by proportion than the former and both have a similar accident rate. The accident severity at T-3 and T-1 are also not significantly different. This probably suggests that, whilst speed might be influential in determining the severity of accidents, some measure of speed, other than just the nominal values may account largely for the level of injury accidents at any given site. Exploratory analysis of the relevant speed and accident data for X-junctions, for example, revealed that the standard deviation of junction approach spot-speeds of vehicles (x) correlated better with personal injury accidents

(y) ($y = 0.031x^2 + 0.17x + 0.47;\ R^2 = 0.37$, n = 34)

than other speed indicators, such as 85-th percentile and mean values.

Both junction types X-2 and X-3 have significantly higher accident severity than type X-1. Between the two of them, however, the difference is marginal. This might be expected, since the major arms of types X-2 and X-3 are both major dual-carriageway arterial roads with similar proportions (35%) of traffic speeds above 50km/h (Salifu, 2002). By contrast, the single carriageway collector or distributor roads typical of junction type X-1 have more than 80 per cent of average spot-speeds below 40km/h.

4.3 Accidents by type of conflict

Table 2 below shows the distribution of accident-types, which is a reflection of the types of conflict at the various types of junction. Admittedly, a much clearer picture of the nature of conflicts and their representation in accidents would have been obtained from the accident data if it had been disaggregated by the various flow-streams at junctions. Unfortunately, the accident database for this case-study is deficient in this respect, as it provides detailed information about turning movements only by the numbers of vehicles undertaking the maneuver and not by the accidents in which such maneuvers are involved.

On the other hand, although the information could have been extracted from the original accident report forms,

Table 2. Accident type distribution by junction type

T-Junctions

Junction type	Accident Type						Total
	Head-on	Rear- end	Side- wipe	Right-angle	Single vehicle	Pedestrian	
T-1	9	35	19	35	8	22	128
T-2	2	11	15	4	4	3	39
T-3	1	9	11	10	1	5	37
T-4	0	10	11	3	0	4	28
T-5	2	20	16	11	3	19	71
T-6	5	13	10	12	3	10	53
Total	19	98	82	75	19	63	356
Percentage	5.3	27.5	23.1	21.1	5.3	17.7	100

X-Junctions

Junction type	Head-on	Rear-end	Side-swipe	Right-angle	Single vehicle	Pedestrian	Total
X-1	5	16	18	36	4	19	98
X-2	9	24	13	26	5	23	100
X-3	2	10	3	14	3	8	40
Total	16	50	34	76	12	50	238
Percentage	6.7	21	14.3	32	5	21	100

this was not considered feasible due to the rather large number of forms involved. In the circumstances, therefore, it was necessary to rely on the accident types, which also give a good indication of the nature of conflicts. It is clear from Table 2 that single vehicle accidents constitute only a small fraction (5%) of all accidents recorded at the case-study junctions. This confirms the expectation that accidents at junctions are predominantly due to conflicts between two or more vehicles, or between vehicles and pedestrians.

Overall, rear-end, side-swipe, right-angle collisions and pedestrian accidents are the four dominant accident types, in order of decreasing percentage at T-junctions, but the relative distribution within each type of T-junction differs markedly from this trend. Whereas rear-end collisions involve vehicles travelling in the same traffic stream, whether on the major or minor road, side-swipes usually involve merging and diverging maneuvers. Right-angle collisions, on the other hand, predominantly involve the near-side major road vehicles who are moving straight through the junction from one arm to the other and left-turning vehicles from the minor road

Junction type T-1 appears to be the most susceptible to right-angle collisions amongst the T-junctions and this may be due, in part, to the potential for minor road vehicles to overshoot the position of the stop-line, accidentally or otherwise, into the path of through vehicles on the major road. The main accident types at this type of junction are right angle, rear-end, pedestrian and side swipes, in order of decreasing percentage. By comparison, the trends for T-5 and T-6, for example, are respectively, rear-end, pedestrian, side-swipe and right-angle and rear-end, right-angle, side-swipe and pedestrian in similar order.

The majority of pedestrian accidents were recorded at T-1 and T-5 type junctions and this would be largely attributable to the locations of these junctions (e.g. how close or far away they are from the CBD) and the level of pedestrian traffic on them. This is supported by the fact that, with the exception of T-6, junction types T-5 and T-1 recorded higher average peak hour pedestrian flows than the rest of the junctions. But the scale of pedestrian accidents at these sites could also be due to some site-specific features, which should become more apparent at the modelling stage when the relationships between site geometry, traffic variables and accidents are examined.

Relative to T-5, T-6 recorded a smaller average percentage of rear-end accidents, although the latter carries about 20 per cent more traffic and about twice the proportion of left-turning major road vehicles than the former. By these indicators, which may be closely related to the incidence of rear-end collisions, T-6 type junctions would have been expected to fare poorer in this respect than T-5. The observed outcome may be connected with the presence of a dedicated storage lane for left-turning major road traffic on T-6, which enables diverging traffic to leave the mainstream before slowing down to execute the turn.

The potential safety benefits of a separate left-turning storage lane on the major road, as obtains on T-6 junctions, may not be limited only to the reduction in incidence of rear-end accidents. By providing refuge for left-turning vehicles into and from the minor road, drivers are presented with the opportunity to wait for adequate safe gaps to leave or join the major traffic stream. This reduces the potential for conflict, and therefore accidents, between major and minor road traffic.

At X-junctions the distribution of accident types overall was right-angle, rear-end, pedestrian and side-swipe, in order of decreasing average percentage. Right-angle accidents stand out much more obviously here (it is consistently the most dominant at all the junction types) than with T-junctions. Such collisions predominantly involve vehicles making a straight transition through the junction from one arm to the other of the same road and the corresponding traffic stream on the other road, although other opportunities for right-angle collisions exist for left-turning vehicles as well. Junction type X-1 appears more particularly prone to right-angle collisions than the other junction types. This is even more evident when it is considered that half the sum of through minor and major road traffic, a proxy for the potential number of conflicts relevant to right angle collisions, is only 3,314 vehicles per day as compared to 7,051 vehicles per day for X-2 and 5,885 vehicles per day for X-3. Thus, although X-1 has potentially less exposure to this type of accident, it still manages to record a high proportion relative to the other types of junction. The general difficulty of clearly identifying the hierarchy of roads at such junctions, which is made worse by the absence of channelisation, may be a major factor in these accidents.

X-2 type junctions, on the other hand, indicate a higher potential for rear-end collisions relative to X-1 and X-3. These account for about 50 per cent of all rear-end collisions at X-junctions, although they evidently had a much smaller proportion (6.1%) of left-turning major road traffic, an important relevant traffic flow stream for rear-end collisions. X-3 and X-1 had 13.8 and 15 percent, respectively, of major road traffic making left-turn manoeuvres. Due to the absence of left-turning storage lanes for major road traffic at X-2 type junctions, it is quite likely that rear-end accidents would arise out of conflicts between cruising through traffic and slowing down left-turning traffic in the inner-lane of the major road. Pedestrian accidents are also most highly represented at X-2 junctions.

4.4 Accidents by type of junction control.

In this case-study, three types of unsignalised junction control were encountered, namely; "stop", "yield" or "give-way" and no control or "none". These control types were compiled based on the posted signs at each junction, therefore, no control or "none" represents the situation where no signs or road markings were present, although that does not necessarily mean that drivers were free to behave as they wished. By convention, at junctions where no specific rules are posted, traffic is expected to follow the rule of a roundabout, albeit invisible in this case. Doing a comparative assessment of the safety records of junctions with these different control types was an important part of meeting the objectives of the current study.

In Table 3 below, essential indicators have been presented to compare the unsafety of the control types as they operated at junctions of the type T-1. Isolating this group from other types of T-junctions, not only provides a more even-handed basis for the intended comparisons but, also an opportunity to see if there is any consistency or trend in traffic control practice. The general picture from Table 3 is that, as the level of control is tightened from "none" through "yield" to "stop", the nominal values of overall accident rate, injury accident rate and accident frequency consistently increase.

Further to that, the differences in the overall accident rates and accident frequencies for the different controls were highly significant (at 1% level). On account of these two indicators, therefore, we can conclude that the unsafety situation at priority junctions worsens with increasing level of control. In terms of accident rates, stop-controlled junctions are about twice and two and a half times as unsafe as "yield" and "no control" junctions, respectively. In any given year, stop-controlled junctions are also likely to record forty per cent more accidents than yield junctions and over two and half times more accidents than junctions at which there is no control. The difference in injury accident rate between no control and yield control junctions was however not statistically significant.

A contentious point that might be advanced, in defense of the apparently poorer safety record of tighter junction controls (e.g. stop control), is that the tightening itself may have been motivated by an existing bad accident situation at the site. It may also be said, that such sites carry more traffic relative to the junctions with more relaxed controls. Unfortunately, these points would tend rather to reinforce the case against adopting the tighter control as a safety intervention, because the situation remains unaffected (at best!) after implementation. In fact, because accident rate, which is the main basis of comparison here, tends to be more favourable to high as opposed to low flow sites, the gulf in safety between stop controlled and other types of junction could actually be worse than portrayed here.

Nevertheless, it is important that reasonable caution is

Table 3 Traffic and accident characteristics by type of control at junction type T-1

Junction control Type	Number of sites	AADT veh/day	Minor road's share of traffic (%)	Overall accident rate (accidents/10^6 vehicles)	Injury accident rate (accidents/10^6 vehicles)	Accident frequency (accidents./site/ year)
STOP	11	12,234 (2,133)*	22.9 (3.5)	0.89 (0.35)	0.26 (0.08)	2.51 (0.92)
YIELD	5	11,484 (1,758)	28.4 (5.4)	0.46 (0.06)	0.19 (0.03)	1.80 (0.23)
NONE	5	9,828 (3,354)	27.8 (1.5)	0.35 (0.15)	0.17 (0.09)	0.93 (0.29)
Overall total (average)	-	11482 (1,386)	25.4 (2.31)	0.66 (0.19)	0.22 (0.05)	1.97 (0.50)

exercised in interpreting the above results. It is quite tempting, for example, to conclude that the safest junctions are those that have no control and, following that, suggest that we can improve safety at stop-controlled junctions by simply removing the controls! Such a view would be overly simplistic and could lead to even more disastrous consequences. Contemplating the replacement of stop with yield control, however, might be a more acceptable prospect, given the potential savings likely to accrue in respect of vehicle operation costs, in addition to the possible safety improvement.

Above all, the results presented here must be interpreted within the context of the range of data covered and the comparative approach adopted. Decisions on safety interventions would have to be based on some notional "acceptable" threshold values of accidents, or accident rates, for each major type of junction and control type examined here, and options for improvement need not be limited to the junction types discussed. It can also be observed from Table 3 that the level of control tends to increase with increasing AADT. Thus, the approach adopted to junction control, it appears, has been to implement stop control at the more highly trafficked junctions and, within that, probably giving preference to those with a much higher major road traffic relative to the minor road. The basis of this assertion is the fact that stop-controlled junctions recorded both the highest AADT and lowest minor road share of traffic. This might sound a prudent approach, since junctions of this nature (without any features on either road) are often formed by roads generally lower down the urban road hierarchy, which are not clearly distinguishable from each other by their geometric features.

The underlying rationale for implementing yield in preference to no control or *vice versa* is less obvious, except in the difference in AADT values for such sites. It appears though, that no control sites would usually have relatively low flows on both major and minor roads. It is also quite likely that, where the flow levels at sites with no control were comparable to others with either stop or yield signs, the non-provision of signing could have been more due to resource constraints of the responsible Road Department than to a deliberate decision not to actively control. The same indicators as in Table 3 are presented in Table 4 for junction types T-2 to T-6.

Similar trends obtain as for junction types T-1, as far as the relative safety records of the different types of control are concerned, although substantial differences can be seen between individual values of the key indicators in the two cases. Whereas accident frequency figures are essentially the same as those for T-1 type junctions, averaged over the different control types, all accident and injury accident rates of T-2 to T-6 type junctions are between one and a half and two times those of T-1 junctions. To confirm this, statistical tests have showed that, whilst the average accident frequency for T-2 to T-6 type junctions are the same as that for T-1 (difference not significant at 95 per cent confidence level), the differences between the average all accident and injury accident rates were highly significant. By implication, this means that, on average, T-junctions without features (i.e. some form of channelisation) are generally more than one-and-a-half times unsafer as those with features. It is, however, slightly unexpected that junctions with features (i.e. some form of channelisation), mostly with dual-carriageways as the major roads, recorded less incidence of injury accident than those without features, because of the possibility of higher operating speeds on the former. A partial explanation of this trend may be that the much larger traffic volumes handled by junctions with features probably "dilute" their injury accident rate figures. Alternatively, as already observed elsewhere, the injury accidents may be more dependent on variability in traffic speeds than actual levels of speed.

Two intriguing aspects of the traffic characteristics of the T-2 to T-6 sites are that, first, those with no control re

Table 4 Traffic and accident characteristics by type of control at T-2 to T-6 type junctions

Junction Control	Number of sites	AADT (vehicles/ day)	Minor road Traffic (%)	All accident rate (accidents/ 10^6 vehicles)	Injury Accident rate (accidents/ 10^6 vehicles)	Accident Frequency (accidents/site /year)
STOP	16	16,995 *1868.9**	18.2 *2.96*	0.46 *0.09*	0.18 *0.04*	2.54 *0.62*
YIELD	17	13,380 *1,575.70*	19.5 *3.3*	0.33 *0.07*	0.1 *0.02*	1.84 *0.42*
NONE	3	15,942 *1,845.48*	25.2 *1.91*	0.2 *0.14*	0.06 *0.03*	1.11 *0.55*
Average (overall)		15,200 *1,276.20*	19.4 *2.2*	0.37 *0.05*	0.13 *0.02*	2.09 *0.35*

corded much higher traffic volumes and minor road's share of traffic than the yield controlled sites. Secondly, the least trafficked sites with features were not only yield controlled, but they also handled far more traffic than sites in the T-1 group, which would have qualified outright for stop control. Perhaps, the only plausible explanation for these observations is the possible element of arbitrariness in traffic control practice, in addition to obvious resource constraints, which mean that the road authorities are unable to implement traffic controls at all junctions in need of them at any one time. It was not possible to do similar comparisons of the accident records of the various unsignalised control types at X-junctions, because only 15 percent of the entire sample covered by the case-study were either yield control or the no control type. Generally speaking, therefore, it would be fair to say that all X-junctions are regulated by two-way stop control on the minor roads, irrespective of the AADT levels, or the relative split of traffic between the major and minor roads.

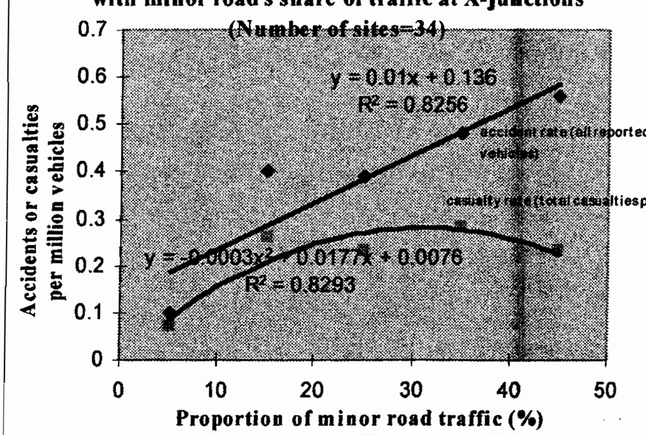
4.5 Safety implications of minor road traffic

The level of traffic on the minor road is one important parameter used as a guide for decisions on the type of control, or the need to upgrade unsignalised junctions, to achieve some set traffic management and safety objectives. Any consideration of the safety threshold limits for unsignalised junctions, therefore, has to include a close examination of the general relationship between minor road traffic and accidents. It is apparent from the discussions in the preceding sections that the proportion of junction traffic on the minor road clearly had a part to play in the differences in some safety indicators of the different types of junctions examined.

To find out if there were any more general relationships, the minor road's share of traffic at each junction and the corresponding accident data were subjected to ordinary regression analysis. When the minor share of traffic was matched against overall accident rates and casualty rates across the spectrum of junction types, it was found that the relationship varied from none at all, for T-1, T-2, and X-3 junctions, through R^2=0.3-0.4, and R^2=0.5-0.7, for T-4, T-5, T-6, X-1 and T-3 and X-2 respectively. Further exploration by aggregating the respective data for all T- and all X-junctions separately gave very good and quite plausible relationships.

As illustrated in Figure 2, for X-junctions, the relation between accident rate and the proportion of minor road traffic is a linear one. It shows that every 10 per cent increase in the minor road's share of traffic, leads to a 0.1 increase in accident rate (all reported accidents per million vehicles). The relation explains just over 80 percent of the variation between the two parameters. The link between accident casualty rate and minor road proportion of traffic at X-junctions, on the other hand is described by a polynomial curve, which means that casualty rate (total casualties per million vehicles) increases with increasing proportion of traffic from the minor road, until it peaks at about 0.27 casualties per million vehicles, corresponding to 29.5 per cent for minor road traffic.

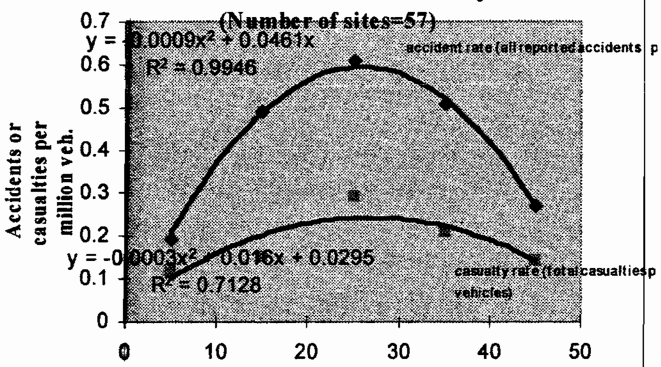
Figure 2. Variation of accident and casualty rates with minor road's share of traffic at X-junctions



It is important to stress that accident rate cannot increase with minor road traffic without bounds. Thus, the trend observed must be understood within the limits of the data presented. The general relation is nonetheless quite plausible, because increasing traffic from the minor road will lead to increasing conflict at unsignalised junctions, and thereby, lead to a higher potential for accidents. It is also a realistic scenario to observe that, as the minor road traffic share increases so does the casualty rate. However, because casualty rate has a close relation with traffic speeds as well, it is expected that this will peak at a point and drop subsequently, as further increases in the share of minor road traffic leads to a general slow down of traffic on all arms of the junction. This critical turning point corresponds to 29.5 per cent for minor road traffic, as earlier stated.

At unsignalised T-junctions, the relation between minor road's share of traffic and casualty rate (see Figure 3) is similar to the one observed for X-junctions. The critical proportion of minor road traffic in this case is 26.7 per cent. The accident rate trend, however, is different. In this case, it follows a polynomial trend, similar to the casualty rate trend, and it peaks at 0.59 accidents per million vehicles for a minor road's traffic share of 25.6 percent. For unsignalised T-junctions, therefore, accident rates fall with casualty rates after both have peaked more or less at the same percentage of minor road traffic. It would appear that accident rate at T-junctions is more sensitive to increases in the minor road traffic than X-junctions, since the rate of increase or fall is much more rapid in the former case. The casualty trends on the other hand have similar gradients and only clearly differ in their turning point values.

Figure 3. Variation of accident and casualty rates with minor road's share of traffic at T-junctions (Number of sites=57)



The fact that casualty and/or accident rates begin to fall beyond the "turning point" values of the minor road's share of junction traffic is suggestive of a potential gridlock situation in which junction capacity is seriously compromised. In other words higher minor road's share of traffic means that the junction is drifting towards congestion, under which condition traffic collisions and casualties would be minimal. It would make sense therefore to suggest that as minor road traffic approaches these critical values for the various junction types there is the need to consider upgrading the level of junction control (from priority to signal-controlled, for example) in order to preserve or even increase junction throughput as well as cut down on the accident and/or casualty rate.

Finally, it is important to note that the regression relationships described above were obtained with a simplified form of the data. Only the averages of accident/casualty rate for five classes between 0.0% and 50.0%, and at intervals of 10% were plotted against the mid-points of the classes. Obviously, this raises queries about the relative weights of these points, since the distribution of junctions in the class intervals was not the same.

However, this was not a major concern, because the exact quantitative relationships themselves were not the main subject of interest. For the purpose of this study, the main idea was to investigate evidence of any systematic relationship that further explained the differences in accident characteristics of the different junction types and hence buttressed the need to use the minor road's share of traffic as an explanatory variable for estimating accident prediction models.

5. CONCLUSIONS

The case-study has enabled more quantitative comparisons to be undertaken of the levels of unsafety (accident potential) at a representative sample of priority-controlled urban junctions, comprising six types of unsignalised T-junctions and three types of X-junctions, classified by the presence or otherwise of some features on either road. The main measure of unsafety was the accident or casualty rate per million vehicles. Generally, junctions without any features (i.e. some form of chanelisation) had an accident potential 1.5 to 2.5 times that of junctions with features. This appeared to affirm the basic need for channelisation, or divisional islands, on one or more approaches of the junction. For junctions with dual carriageway arterial roads, the presence of a dedicated left-turning storage lane for major road vehicles appeared to enhance safety as well as junction capacity. Stop-controlled junctions were also statistically significantly less safe than those with either yield or no control.

The minor road's share of traffic appeared to be one of the most influential factors of unsafety. Initial exploratory analysis using ordinary regression techniques showed that it had very high correlation with accident and casualty rates per million vehicles. The relationships identified provide a good basis for determining the limits of deployment of priority control given the proportion of traffic entering the junction from the minor road. From the results it would appear prudent to consider upgrading the priority control at unsignalised T-junctions when the proportion of traffic is approaching the range 25-27%. The corresponding critical proportion of minor road traffic for X-junctions is between 29 and 30%.

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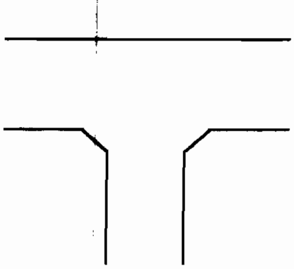
Appendix 1. Typology of Junctions

T-1



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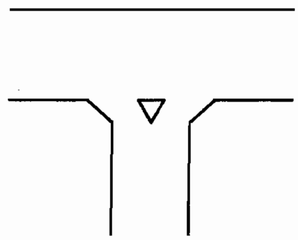

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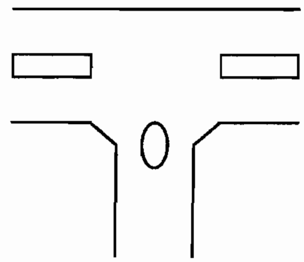

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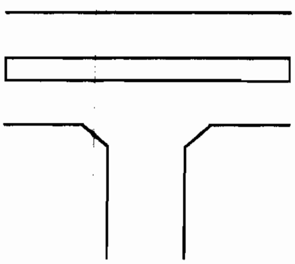

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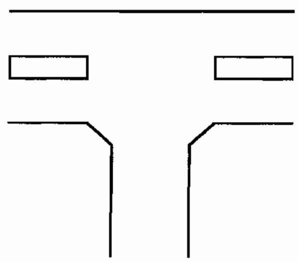

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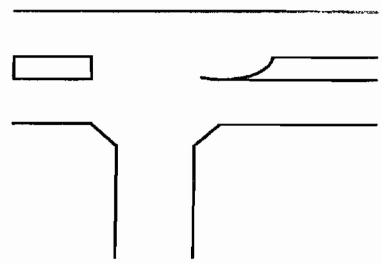
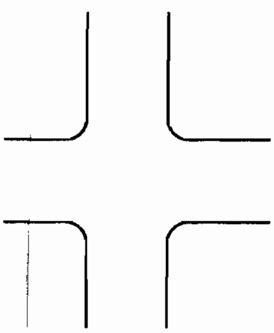
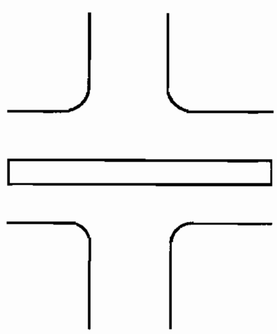


X-1



X-2



X-3