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EVALUATING THE CONTRIBUTION OF PHYSICAL PARAMETERS ON THE SAFETY OF UNSIGNALIZED INTERSECTIONS

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Abstract

Safety of any particular Road way facility cannot be attributed to set of parameters specific to a certain domain. Unsignalized intersections are no exceptions, thus, making them an important area of study. This paper presents the results of the analysis of four parameters, namely road width, traffic control, lane marking and landuse; and their sub-class on the safety of unsignalized intersections. The raw accident data was obtained from MIROS (Malaysian Institute of Road Safety Research). It was then reduced for descriptive analysis. Hypothesis testing was performed to assess the significance of all parameters and severity analysis was done to accomplish micro scale examination of each sub-class. The results show that landuse and lane marking are statistically significant. They are important variables to predict accidents whereas traffic control and road width are not significant. Intersections located in city with single line lane marking having no control and major road width greater than 9 meters were found to have the highest severity indices.

Keywords: Road safety, Unsignalized intersection, Accident severity, Hypothesis testing, Severity analysis.

1. Introduction

Scientific study of accident occurrence and its causes has influenced the design of road infrastructure over the period of time. Unsignalized intersections being one of them [1]. They constitute a huge number among all the fixed control facilities provided on the Road Infrastructure of Malaysia. Hence they contribute equally in the total number of accidents that occur on Malaysian roads. This makes them an important area of study. Obtaining zero crash count on any type of road facility is almost impossible but reduction in the severity of accident is achievable through proper examination of contributing factors and subsequent improvements in the design. The type of factors being analyzed dictates the model form used for the prediction of accident severity and cause identification of their occurrence. Hence selection of appropriate factors is vital in crash severity modelling. Accident data in Malaysia is recorded by Police [2] on standard forms known as POL 27. It is then transferred to MIROS (Malaysian Institute of Road Safety Research) [3] for digitization and development of accident database. The data recorded contains several attributers such as number of accidents, accident severity, vehicle type, road width, shoulder width, lane marking, control type, geometry, landuse, weather and time of accident. This paper focuses on the analysis of 442 unsignalized intersections in the northern part of West Malaysia. The geometric parameters that affect crash severity are examined and their results are discussed.

2. Literature Review

There are different ways to look into the subject of road safety and one of them is “if the user makes a mistake it does not mean he has to die for it”. Keeping in view the above statement as the primary goal of safety improvement of unsignalized intersections, many researchers had tried to make design improvements by modelling the geometric and traffic parameters that significantly affect the occurrence of crashes. Among them the prominent parameters are major and minor road volume, major and minor road approach speed, type of control such as Yield sign, Stop sign, Stop line or no control, gap/lag acceptance, traffic conflict, Post Encroachment Time (PET) and Time To Collision (TTC) [4].

2.1. Volume as measure of safety

First, reports on the accident analysis of cross roads and junctions are as old as 1950’s [4]. The earliest accident analysis involved the measurement of indices such as number of accidents per left/right turning movement [5]. Apart from major and minor road volumes researchers started using STOP sign as a measure of intersection safety. As stop controlled intersections require the minor road drivers to come to a complete halt before entering an intersection, it was also argued that introduction of a stop sign also unnecessarily increases the number of accidents [6]. In a later study [7, 8] it was concluded, using Generalized Linear Modelling (GLM), that introduction of any kind of control measure to an uncontrolled intersection offers greater safety, especially at 4-leg intersections where STOP signs were introduced instead of no control. In late 1980s emphasis on other geometric features, along with major minor road volumes and STOP sign provisions, on accidents started taking place. These geometric features included clear sight distances from major and minor roads, grade, curve, type of median (raised, mountable, flush, none), raised pavement markers, rumble strips and separate turning lanes [4, 9].

2.2. Speed as measure of safety

Use of gap acceptance as a parameter for modeling accidents had been argued in previous research [4, 6], until it was used extensively by [10]. Unsignalized intersections are a facility which is usually provided on low volume roads. This provokes the drivers to increase their speeds [4]. In a comprehensive study [11] involving the effect of time gap, speed and time to cross on the accident probability of minor stream vehicles assumed all the vehicles of major road stream to be 'Free Vehicles'. A logit model was derived which provides the probability of crossing against not crossing the major stream, given a set of values for the time gap, major road approach speed and time required to cross the intersection by the minor road vehicle. The model was then extrapolated theoretically for conflict and accident probabilities respectively. It was found that the chances of a minor stream vehicle colliding with a major stream vehicle increases with the increase in major stream vehicles' approach speed. It was concluded that the increase in accident probability indicates the speed dependency of gap acceptance behavior. In early road and traffic design manuals such as AASHTO [12] and HCM [13], it was denied that the approach speed of major road vehicles has any effect on the gap acceptance by minor road vehicles. A study [14] involving driver's perception of major road vehicles' speed clearly indicated that the decision of accepting or rejecting a gap is purely based on the distance between them and the major road vehicle. This is because for the same time headway ; the distance headway between major road vehicles will increase with the increase in speed, thus creating a false perception in the mind of the minor road vehicles driver that the oncoming vehicle is far away and it safer to accept the gap. Therefore, clearly misjudging the time required for completing their crossing or turning manoeuvre resulting in an accident.

2.3. Alternative measures

Since accidents occur rarely and those which occur are not 100% reported, therefore, an alternative was required to estimate the probability of accidents at intersections with little or no history of accident occurrence at all. Traffic conflicts were considered to be the solution to this problem [4]; hence microsimulation technique was utilized to generate traffic conflicts at three legged and four legged unsignalized intersections in Italy using AIMSUN simulation software along with SSAM software [15]. Intersection related traffic parameters such as Post Encroachment Time (PET) and Time To Collision (TTC) were used to identify critical conflicts i.e. a collision is very probable to occur if the values of TTC and PET lie within the range of 0 to 1.5 seconds and 0 to 5 seconds respectively. The number of accidents predicted by the conflict model was then compared with the conventional model which uses volumes of major and minor road as explanatory variables. Although major road time headway, which is a very important parameter, was not used in the modelling process but it was concluded that traffic conflicts can be successfully utilized as an alternative to actual crashes for estimating accidents per year at unsignalized intersections [4].

3. Study Data

In Malaysia the Royal Malaysian Police [2] records the accident information on standard forms known as POL 27 which are then transferred to MIROS (Malaysian Institute of Road Safety Research) [3] to update the accident database. The information recorded consists of numerous types of data, such as crash information which includes number of accidents, accident severity and vehicle type, field information such as major/minor road width, lane marking, control type, geometry and location, and miscellaneous information such as weather, time of accident, and Average Annual Daily Traffic (AADT). Since most of the above information is recorded by Police and later digitized in raw form, it is required to reduce the above information customizing it for specific analysis.

The raw data collected from MIROS contains several parameters such as driver characteristics, vehicle characteristics, intersection characteristics, traffic control, landuse and environmental characteristics. It was reduced to four specific parameters relevant to the context of intersection geometry for analysis. The parameters selected are major road width, landuse, lane marking and control. The landuse comprised of four subtypes namely city, town, small town and rural. The lane marking comprised of five subtypes namely single, double, one-way, divider and no marking. The traffic control comprised of three subtypes namely stop sign/line, yellow box and no control. Table 1 gives a brief description of the parameters and their subclass.

Since the data obtained from MIROS contained several readings in which some or all of the parameters required for analysis were missing. Therefore, all data points with missing values were omitted reducing them to only those which were complete in every respect. Thus, a total of 442 data points were selected out of 180,000 readings. Accident data for six years (2006-2011) was analysed for this study.

4. Analysis of the Data

The data was analyzed separately for each parameter. The effect of each subclass on the overall behaviour of accident occurrence was studied. Since, the parameter of road width did not contain any subclass, it was divided into three different ranges. The first range contained intersections with major road width between 0 to 9 meters. The second range contained intersections with major road width between 9.1 to 15 meters. The third range contained intersections with major road width greater than 15 meters. This division was done in order to have some comparison within the parameter and to extract meaningful results.

4.1. Effect of land use

Malaysia is a country that has a vast road infrastructure spread over a diversified landuse. Although most of the population is saturated into cities and towns but small residential towns and rural areas are also inhibited by considerable number of residents [1]. Since the rural road infrastructure is equally developed in comparison to urban, it was expected that share of accidents will be similar. But the analysis revealed that the number of accidents occurring in cities is far more less then towns, small towns and rural areas. Detailed investigation was performed by dividing the accident data with respect to severity as shown in Fig. 1. In cities unsignalized intersections are mostly provided in areas with lesser traffic volume and smaller major road width while in other landuse they are provided on every location where the volume was less. This proved to be the reason for the under representation of cities in the overall number of accidents occurring in different landuse. As severity is directly proportional to the speed with which a vehicle collides with another vehicle or fixed object the areas where the volume was less the speed of the vehicles were high resulting into more severe accidents. The highest number of accidents that were observed was of slight injury as compared to fatal and damage only accidents. Severe injury accidents were the second most observed category among different landuse. In general the overall severity of accidents was found to be identical for all landuse except cities [1].

Table 1. Description of Parameters and Their Subclass.

Parameter	Subclass	Description
Road Width	------------	Major road width measured in meters
Landuse	**City**	Urban area comprising of large business centres and shopping plazas
	Town	Urban area comprising of smaller business centres and housing plazas
	Small Town	Semi-urban area chiefly comprising of housing societies
	Rural	Rural area with vegetation being the dominant landuse
Lane Marking	**Single**	Single line lane marking at the center of the major road for separation of traffic moving in opposite direction
	Double	Double line lane marking at the center of the major road for separation of traffic moving in opposite direction
	One-Way	Traffic moving in only one direction on the major road
	Divider	Two way divided major road separated by concrete or grass median
	No Marking	No marking on major road
Traffic Control	**Stop Sign/Line**	Traffic controlled by Stop sign or Stop line on the minor road
	Yellow Box	Traffic controlled by Yellow Box on the major road
	No Control	No control of traffic on minor road

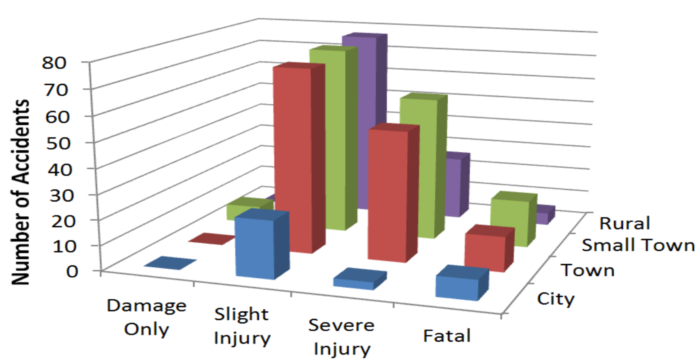

Fig. 1. Number of Accidents per Landuse versus Severity [1].

4.2. Effect of lane marking

Lane marking is an important parameter of traffic control. It reflects the situation of traffic prevalent on the major road. Roads with smaller width and lesser volume usually have no marking while single and double lane marking is provided where the volume is higher. Roads with substantial volume are either provided with concrete or grass median to separate the traffic moving in opposite direction or converted to one way facilities. Analysis of the data showed that roads with single line lane marking are overrepresented in the total number of accidents that occurred on various lane markings. In order to investigate further the data was sliced into different categories with respect to severity as shown in Fig. 2. In comparison roads with no marking, one way traffic or divider had almost no accidents. Variation in terms of severity was observed only on roads with single and double line lane markings with slight and severe injury accidents being the major contributors. It was found that single and double line lane markings are futile in terms traffic control [1]. Because the number of accidents that occurred on them were very high as compared to other types of lane markings provided. This study also proves that lane marking can be a key parameter in accident investigation and black spot analysis. The examination of the data also elaborates the effectiveness of one way traffic.

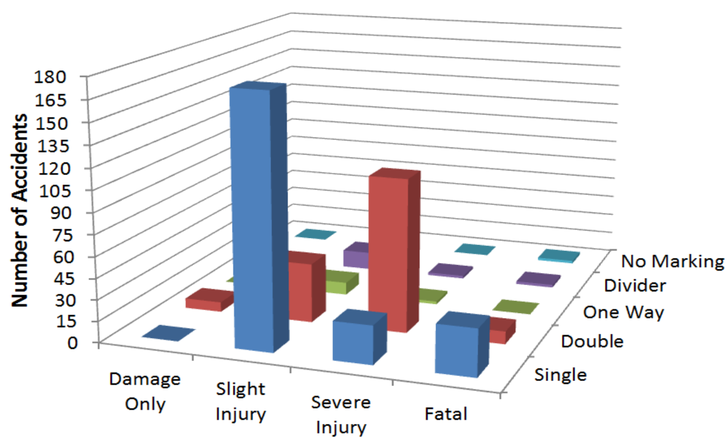

Fig. 2. Number of Accidents per Lane Marking versus Severity [1].

4.3. Effect of traffic control

There are two types of traffic control mostly provided on unsignalized intersections in Malaysia. Stop signs or Stop lines being the most common while Yellow box is also provided where the major road traffic volume is higher. Usually no control on minor road is provided where the volume is less. This proved to be a disaster in terms of road safety. Because almost all the accidents that occurred on unsignalized intersections were on locations where there was no control of traffic on minor road. With the purpose of investigating further the data was alienated into different categories with respect to severity as shown in Fig. 3. As the total number of accidents occurring on intersections with no control was higher their contribution in slight, severe and fatal accidents was also greater. No variation was observed among other types of control such as stop/yellow line and yellow box in terms of severity. No control on minor road gave the drivers an open invitation to take risk and drive carelessly. This resulted into more accidents as compared to intersections with any other kind of traffic control. Therefore, lack of control on minor road was found to be an important cause of accident occurrence. Intersections with very weak control, such as stop/yellow line only, performed very well in terms of road safety as compared to intersections with no control at all [1].

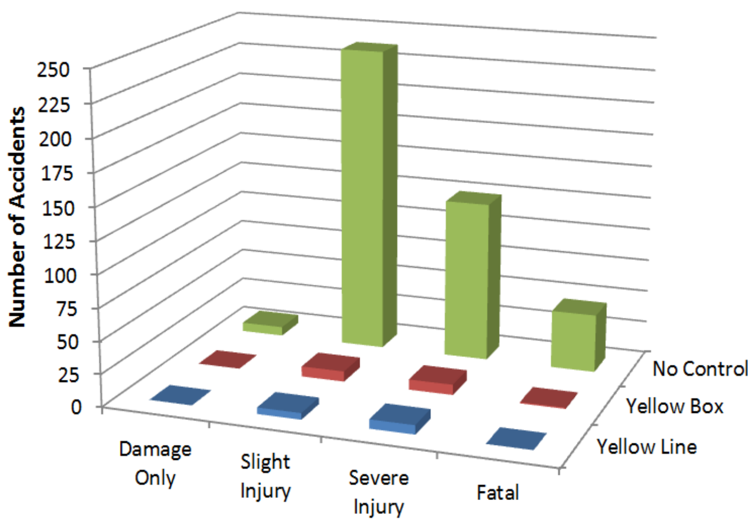

Fig. 3. Number of Accidents per Traffic Control versus Severity [1].

4.4. Effect of road width

The width of major road plays an important role in the overall safety of unsignalized intersections along with speed and sight distance. The greater will be the road width the more will be the time required by the minor road vehicles to complete their manoeuvre. Thus, the risk of accident associated with unsignalized intersections increases with the increase in major road width. The parameter of road width was divided into three different ranges. The first range contained intersections with major road width between 0 to 9 meters. The second range contained intersections with major road width between 9.1 to 15 meters. The third range contained intersections with major road width greater than 15 meters. This division was made in order to have some comparison within the parameter and to extract meaningful results. The total number of accidents occurring on intersections with width greater then fifteen meters was very less as compared to the other two ranges. Reason behind this is the lesser number of unsignalized intersections on wider roads. When data was further divided with respect to accident severity, as shown in Fig. 4, it was found that there was not much variation among accidents occurring on intersections with width greater than fifteen meters in terms of severity. Contrary to it all types of accidents occurred on intersections with width between 0 to 9 meters and 9 to 15 meters.

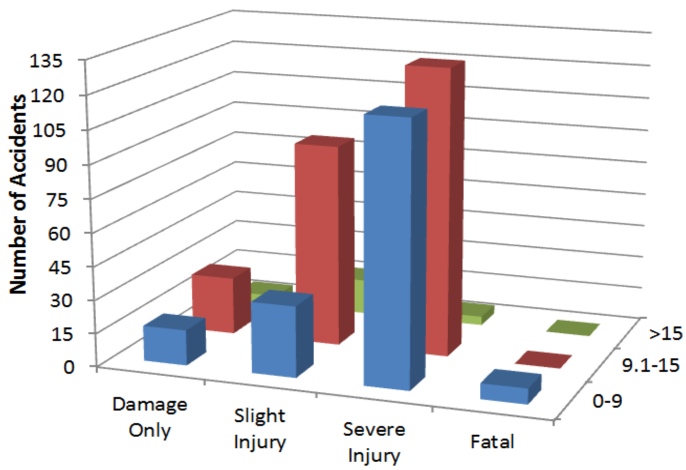

Fig. 4. Number of Accidents per Major Road Width versus Severity [1].

Macro-scale analysis of all intersections falling into each road width confirms the escalation of risk of accident with the increase in major road width. The frequency histogram shown in Fig. 5 indicates the number of accidents that occurred in each road width class (measured in meters) with the highest being 111 accidents occurring on intersections with major road width between 11.1 to 12 meters. Analysis of the data shows that almost 40% of the accidents that occurred on unsignalized intersections were on major road widths between nine to twelve meters. Since, the numbers of intersections that fall into the range of the width class mentioned above are more, they contribute equally in terms of number of accidents. This is the target range of intersections requiring improvement in terms of road safety.

Fig. 5. Frequency Histogram of Accidents versus Road Width Class.

4.5. Hypothesis testing

An important method to determine whether a parameter contributes in the safety of an unsignalized intersection is to perform Hypothesis testing. Accordingly in this procedure first a null hypothesis 'H_o' is declared for all the four parameters. It states that accidents and landuse / lane marking / traffic control / road width are independent of each other. The alternate hypothesis 'H_1" is the vice versa of the null hypothesis. A very small rejection region of 0.05 was selected so that the null hypothesis could be rejected with 95% confidence. The accident severity was reduced to only two types namely fatal and non-fatal. The χ^2-test has been used to determine whether the selected parameters are dependant or otherwise. The results show that the null hypothesis is rejected for landuse (χ^2 = 10.540, p-value = 0.015) and lane marking (χ^2 = 7.775, p-value = 0.020) indicating that accidents and landuse as well as accidents and lane marking are dependent on each other. Contrary to it the null hypothesis is accepted for traffic control (χ^2 = 1.612, p-value = 0.239) and road width (χ^2 = 0.369, p-value = 0.633) indicating that accidents and traffic control as well as accidents and road width are independent of each other. This testifies that emphasis should be paid to the location and lane marking of intersections to decrease the severity of accidents. These two parameters indirectly indicate the effect of volume and traffic mix of vehicles using a particular intersection under analysis. It clearly signifies that higher the number of vulnerable vehicles flowing through an intersection the more severe the accidents will be. Landuse and lane marking are also correlated with another important parameter which is speed of the major road serving the intersection. Intersections located in areas with lesser volume will have higher speeds resulting into more severe accidents. Thus the results of the hypothesis testing can be used to identify the target attributes of hazardous intersections needing most attention for safety improvement.

4.6. Severity analysis

A more direct method of evaluating the effect of each parameter on the safety reduction of unsignalized intersections is to conduct severity analysis. It is a simple technique in which the "Severity Index" of each sub-class falling into each parameter is calculated and the results are compared. Severity Index can be defined as the number of deaths per 100 accidents occurring at an intersection [16]. It is a measure of the seriousness of the kind of accidents occurring at any intersection or roadway facility. It can be calculated by the following formula

$$Severity\ Index = \frac{Fatal\ Accidents}{All\ Accidents} \times 100 \tag{1}$$

As it provides a percentage of deaths occurring at a particular location, it serves as the best identifier of accident blackspots. In the context of this paper it has been used to identify the most critical subclass contributing in most deaths. Within the parameter of landuse the total number of deaths occurring in city, town, small town and rural areas were 8, 14, 19 and 5 respectively. When they were divided by the total number of accidents in each subclass their severity index was found to be 24, 10, 12 and 5 percent respectively. Similarly within the parameter of lane marking the severity indices for single line, double line, and others were found to be 14, 5, and 10 percent respectively. For intersections with traffic control and without traffic control the indices were found to be 3 and 11 percent respectively within the parameter of traffic control. For road width the indices were 10 and 11 for 0-9 meters and greater than 9 meters respectively. A comparative analysis of all severity indices is shown in Fig. 6.

It is interesting to notice that no deaths occurred on intersections where the major road traffic was one way. This proves that it is an effective method of reducing the severity of accidents especially on roads where the volume is high. No fatal accident occurred on intersections with yellow line as the traffic control although the severity index was quite high for intersections with yellow boxes as traffic control. The reason for this anomaly could be the traffic mix prevalent in the areas where these intersections were located. Although divided roadways serve as a very effective method of traffic regulation but the occurrence of fatal accidents on such intersections suggest that the problem lies within the geometry and not the traffic control of the intersection. Inappropriate sight distances and exceeding of speed limit by major road drivers could be the causes behind the crash deaths occurring on divided roadway intersections. The overall analysis indicates that the most critical accidents occur in cities with intersections having single lane marking, no traffic control and located on major roads with width greater than 9 meters.

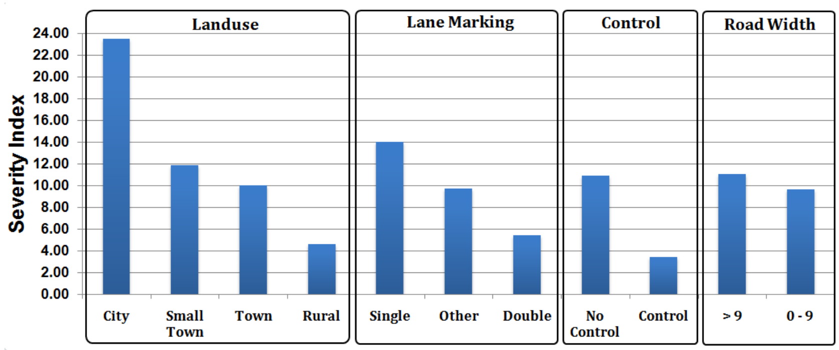

Fig. 6. Severity Index of Each Sub-Class for All Parameters.

5. Results and Discussion

The results of two different types of analysis are presented here in Table 2. Contradiction between the percentages and the severity indices show that the seriousness of accidents cannot be judged in terms of numbers. It can be clearly seen that the percentage of accidents that occurred in small town are higher than the ones that occurred in cities. But the high severity index for city suggests that although the number of accidents that occurred is less but the ones that occurred were fatal. Hence the state of safety of intersections located in cities is poorer as compared to the ones located in other landuse. Within the parameter of lane marking only 9% of the total accidents that occurred were on intersections with no lane marking but most of them were fatal. This gave a significant rise to the severity index of this subclass. Although 53% accidents occurred on intersections marked with single line but the severity index of intersections with other type of lane markings including the ones with no marking is also significant. Therefore, equal attention is required to be paid to all subclasses to improve their safety. In the case of traffic control also the percentage of accidents occurring at intersections with control and without control are 7 and 93 percent respectively but their severity indices are 3 and 11. This shows that the numbers of accidents occurring at uncontrolled intersections are ten times higher as compared to controlled ones but there severity is only thrice as much. Thus, intersections having traffic control also cannot be neglected in terms of safety improvements. Intersections with higher major road width require more time by minor road vehicles to complete their manoeuvre. This results into more fatal crashes as proven by the analysis. Since, the number of intersections with width greater than 9 meters is more their contribution in the total number of accidents is also supposed to be more, but their severity index is almost the same. Hence, treatment of intersections with smaller major road widths is also critical along with intersections having greater major road width. In general intersections laying in city with no lane marking having no control with major road width greater than 9 meters have been found to be the most critical.

Table 2. Total Number of Accidents, Percentage and Severity Index of Each Subclass.

Parameter	Sub-class	Total number of accidents	Percentage	Severity Index
Landuse	**City**	34	8	24
	Small Town	160	36	12
	Town	140	32	10
	Rural	108	24	5
Lane Marking	**Single**	235	53	14
	Other	41	9	10
	Double	166	38	5
Control	**No Control**	413	93	11
	Control	29	7	3
Road Width	**> 9**	270	61	11
	0 – 9	172	39	10

6. Conclusion and Recommendation

This study has shown that accident occurrence at unsignalized intersections can be effectively analyzed. Different severity indices are explored as compared to number of accidents for each parameter. The results obtained are highly relevant and highlight the core cause of accident occurrence that makes an intersection vulnerable. Hence, the necessary action taken in response will be effective and will greatly reduce the accident risk. Thus, improving the overall safety of the road infrastructure.

Although the effect of parameters such as traffic control and road width are not statistically significant but the results of severity analysis show that they are not redundant. Other researchers [17-20], have also used the above parameters in their analysis and obtained statistical results conformal to the ones presented in this paper.

It is concluded that all the intersections laying in city with single line lane marking having no control and major road width greater than 9 meters should be treated radically for safety improvement. It is further concluded that if only number of accidents are looked at they will present a false picture of the situation on ground. Because the higher the number of intersections falling into each sub-classes the more will be their representation. Therefore it is necessary to observe the severity index for each sub-class. This will depict a true image about the criticality of accidents occurring in each sub-class within a parameter. Accident data should be classified in terms of geometric and control parameters for effective utilization in severity analysis. Parameters such as road width, landuse, lane marking, and traffic control provide the key factors responsible for accident occurrence. It is recommended that localized treatment can be provided to intersections with single lane marking by constructing concrete or grass median in the effective area of the intersection. Another option is to convert the major road into one way facility if the volume is high. Since, provision of Stop sign and/or Stop line greatly reduces the number of accidents occurring at unsignalized intersections. Therefore, all intersections with no control should be furnished with stop signs and stop lines [1]. This will contribute heavily towards their risk reduction.

It is suggested that detailed analysis should be conducted using traffic parameters like volume and speed to probe further into the cause identification of the severity of accidents. Factors like type of vehicle, reported in most crashes, can be utilized for addressing the anomalies associated with traffic control and lane marking. Traffic mix of each landuse can be incorporated to explore the cause of high severity index observed in cities.

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