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A Study on Intersection Typology and Road Safety: Case of Mumbai

(Case Study Paper for EST Plenary Session-3)

Final Draft

This background paper has been prepared by Binoy Mascarenhas and Akhila Suri, WRI India for the Eleventh Regional EST Forum in Asia. The views expressed herein are those of the author only and do not necessarily reflect the views of the United Nations.

A study on intersection typology and road safety: Case of Mumbai

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Background

An intersection is a location where roads merge or cross each other, thus putting traffic from different directions into potential conflict. Within cities, intersections tend to have a disproportionately higher share of road crashes, compared to midblock sections of road. For instance, in Mumbai, 20 out of the 52 identified blackspots in the city, (locations with a high crash-risk), are situated at intersections[1]. In terms of total road area, intersections take up only a fraction of road space; yet they are responsible for 38% of all high-crash risk zones in the city[1].

Poor intersection geometry can be a significant factor contributing to crash risk. A poorly designed intersection may unduly force vehicles into conflict situations or aggravate blind-spots, due to misaligned traffic lanes. A large, undefined intersection area may encourage over-speeding or dangerous overtaking. Inadequate infrastructure and incomplete road elements can also play a role in increasing crash risk. For example, missing pedestrian crossings, lack of pedestrian refuges, poor quality footpaths, etc. all contribute to an increased crash risk.

Street design guidelines, including those developed by the Indian Road Congress (IRC) are, in many cases, inadequate to deal with the complexities of intersection design in the urban Indian context. This is because the existing built environment does not always adhere to the basic standards upon which the recommended street design templates can be applied. Typically, street design guidelines cover only standard cases, such as 4-arm intersections at perfect right-angles; or 3-arm Y-intersections or T-intersections. However, in Indian cities, one often faces situations that defer from these templates.

This paper seeks to document the multiplicity of safety issues created by different intersection typologies, using Mumbai as a case-study. In this paper, we have analysed high-risk intersections, (known as blackspots), and categorized these intersections across various parameters. Examples of actual intersections in Mumbai are used to illustrate the differences from standard intersection guidelines.

Mumbai road safety overview

Mumbai has approximately 2,000 km of roads, which cover 8.16% of the city's area[2]. An average of 546 fatal crashes occur on these roads every year[3]. Between 2011 and 2016, 3,417 people died in road crashes in Mumbai[3]. Although the absolute crash fatality numbers in Mumbai are high, the crash fatality rate, (deaths per 100,000 population), is comparatively low at 4.5[3]. This is because of the high population base, given that Mumbai is a large metropolitan city. However, it must be noted that a large number of fatal crashes happen within the urban agglomeration of Mumbai, but outside the municipal limits of the city, and hence, are not enumerated in the city's crash figures.

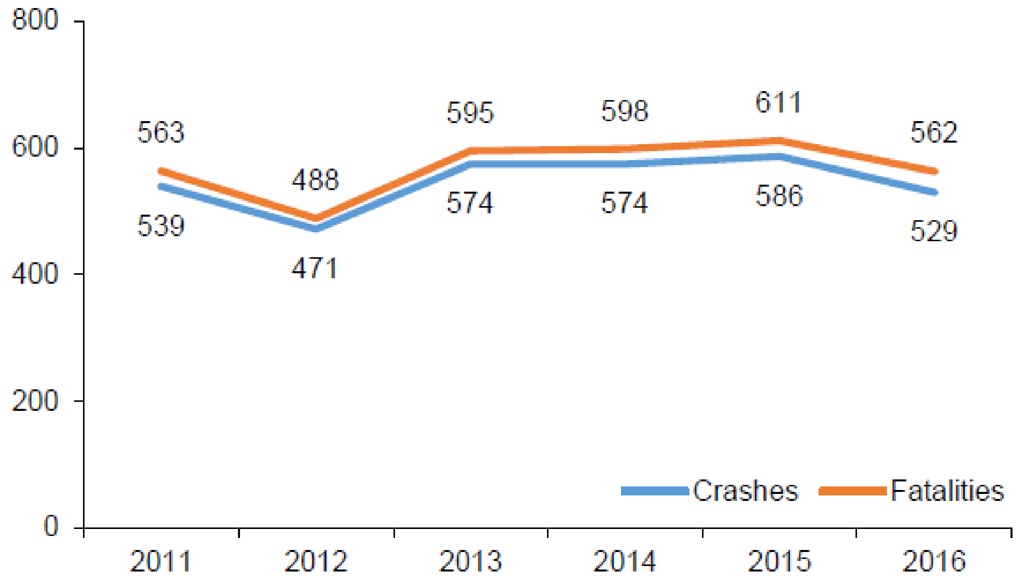

Figure 1:Number of fatalities and fatal crashes from 2011 to 2016[3]

As per the Comprehensive Mobility Plan for Greater Mumbai (2016), walking is the predominant mode of transport in Mumbai, where 51% of all trips in the city are made on foot. In addition, 60% of public transport trips have a walking component. This high share of walking trips is also reflected in the safety numbers, where 57% of all road crash deaths are of pedestrians[3]. Figure 2 shows the distribution of road fatalities by travel mode for the year 2015. The second most vulnerable group is of motorcycle riders comprising 34% of road fatalities[3].

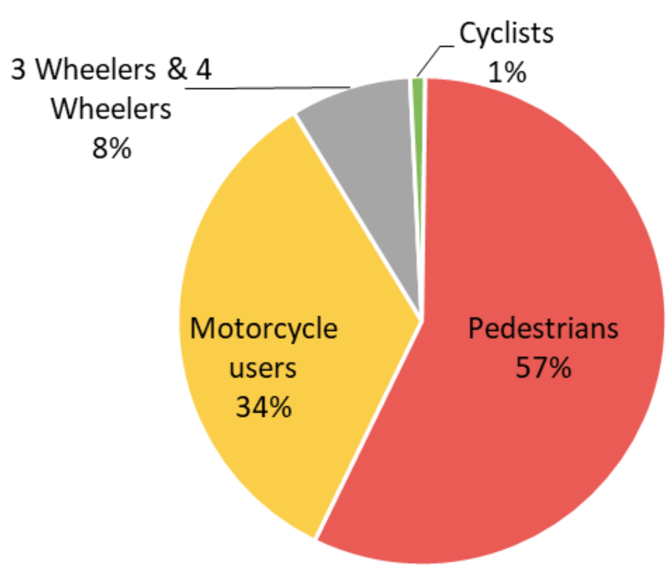

Figure 2: Share of fatalities in Mumbai in 2015 by Road User Type[3]

In half of all fatal pedestrian crashes, the other vehicle involved was a car or a commercial vehicle, as indicated in Figure 3. In 20% of cases, the other vehicle was a motorcycle.

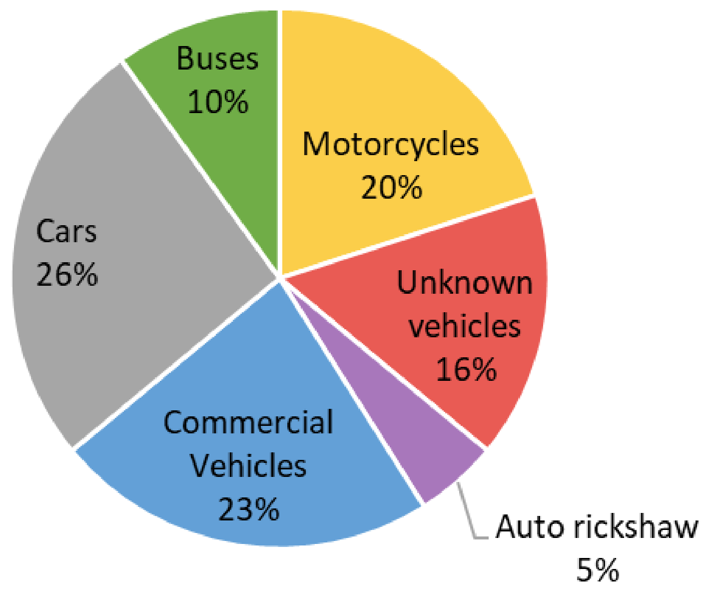

Figure 3: Pedestrian Fatalities by Vehicle Involved – Mumbai, 2015[3]

An overview of blackspots in Mumbai

In 2018, the Mumbai Traffic Police released a study in collaboration with Vital Strategies under the Bloomberg Initiative for Global Road Safety, identifying 52 blackspots in the city. These are locations that have witnessed a high number of severe or fatal crashes in the last 3 years. 20 of these blackspots are located either at or within 30 metres distance of an intersection, which is equal to 38% of all the blackspots[1]. Given that intersections take up only a fraction of road space, their share in total blackspots is disproportionately high. Figure 4 shows the location of these blackspots in Mumbai. From 2014 to 2017, there have been 157 deaths due to crashes and 950 people have been grievously injured at these blackspots. 32% of all fatal crashes in Mumbai have taken place at just these 52 locations[1].

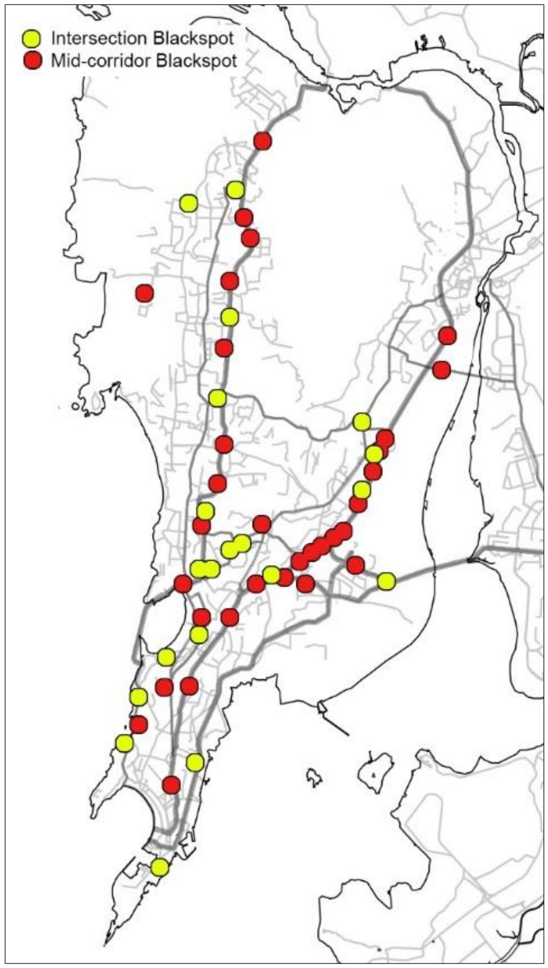

Figure 4: Mumbai Blackspot Map

The blackspots are predominantly concentrated on two major arterial roads in Mumbai, namely the Eastern Express Highway (EEH) and the Western Express Highways (WEH). These two roads are the most important arterials of the city, and carry much of the traffic from the residential suburbs in the north of the city to the commercial centres in the south. There is approximately 1 blackspot every kilometre across a 14 km stretch on EEH and across a 16 km stretch on WEH. Together, they account for approximately 75% of road deaths at Mumbai's blackspots. The adjacent land uses are different for each of these highways. WEH cuts through dense neighbourhoods such as Andheri, Santa Cruz, Khar and Bandra, while EEH is abutted by large privately owned industrial land parcels on one side and marshlands on the other, between Ghatkopar and Vikhroli.

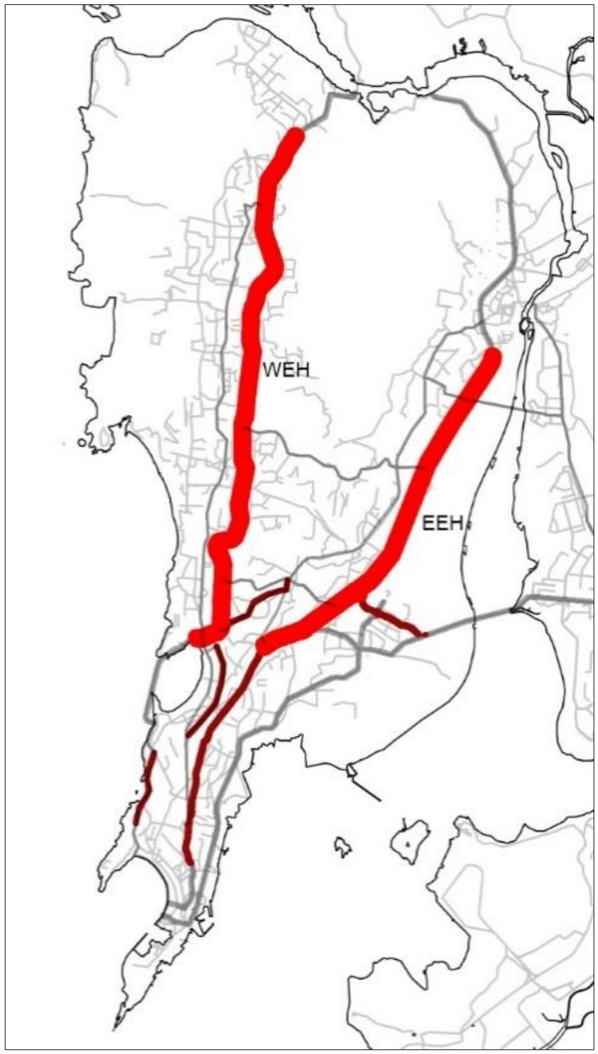

Figure 5: Roads in Mumbai with major blackspots

Other roads with 2 to 4 blackspots in Mumbai are the Ghatkopar-Mankhurd Link Road, BKC Road, Senapati Bapat Marg, Lala Lajpatrai Marg and Dr Babasaheb Ambedkar Road. These roads are predominantly sub-arterial roads, and also carry a significant volume of intra-city traffic.

Intersection blackspots in Mumbai

As mentioned earlier, there are 20 intersections in Mumbai that have been designated as blackspots, which is about 38% of the total number of blackspots in the city. From 2014 to 2017, there have been 416 crashes at these locations, 32% of which have been fatal. 30% of the fatalities at all blackspots occurred at these intersections[1].

In determining the typology of these intersections, it is observed that 65% have 4 arms. Together, they account for 70% of the fatal and grievous crashes occurring at intersection blackspots. 3 arm intersections account for 30% of the intersection blackspots, which were responsible for 24% of fatal crashes and 28% of grievous crashes[1]. There is only one 6 arm intersection on the list of blackspots, which is known as Worli Naka, located in south-central Mumbai.

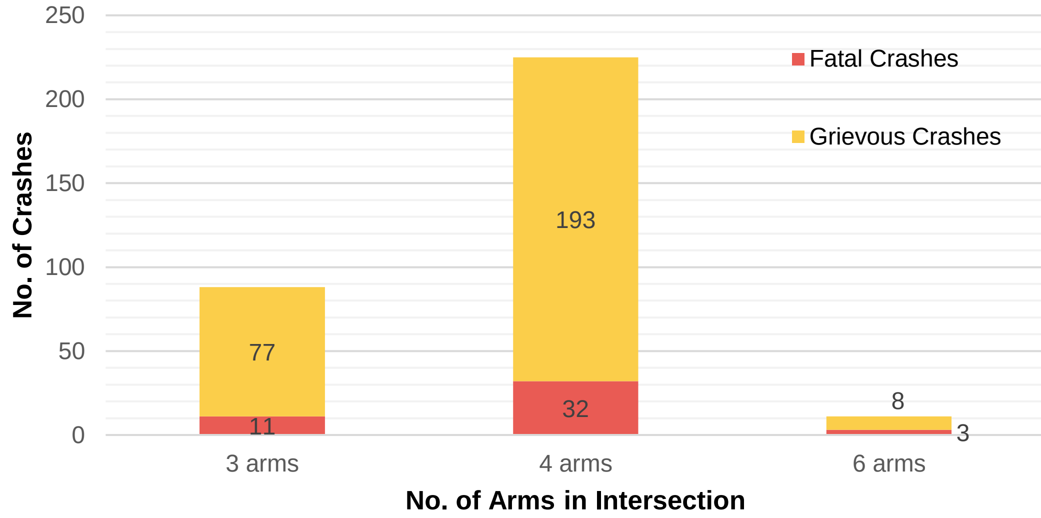

Figure 6: Distribution of Crashes across Intersection Types

Almost 40% of the fatal crashes occurring at these blackspots take place between 10.00 PM to 04.00 AM[1], as seen in Figure 7, despite the significantly lower volume of traffic during this time. Inadequate street lighting, coupled by excessive speeding and non-functioning traffic lights could be factors in explaining the higher crash frequency during this time period.

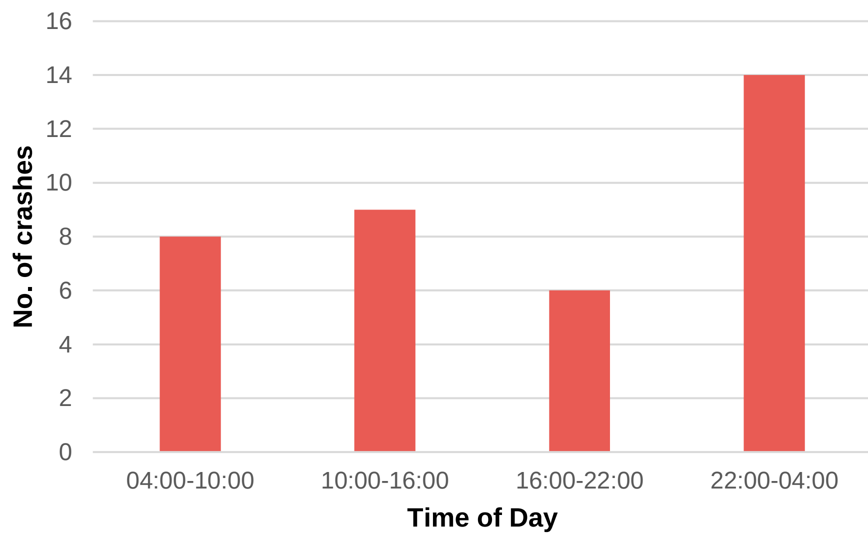

Figure 7: Time of Fatal Crashes at Intersection Blackspots

The land-use around 70% of these intersections is largely mixed and commercial in nature. This includes the redeveloped industrial lands along EEH.

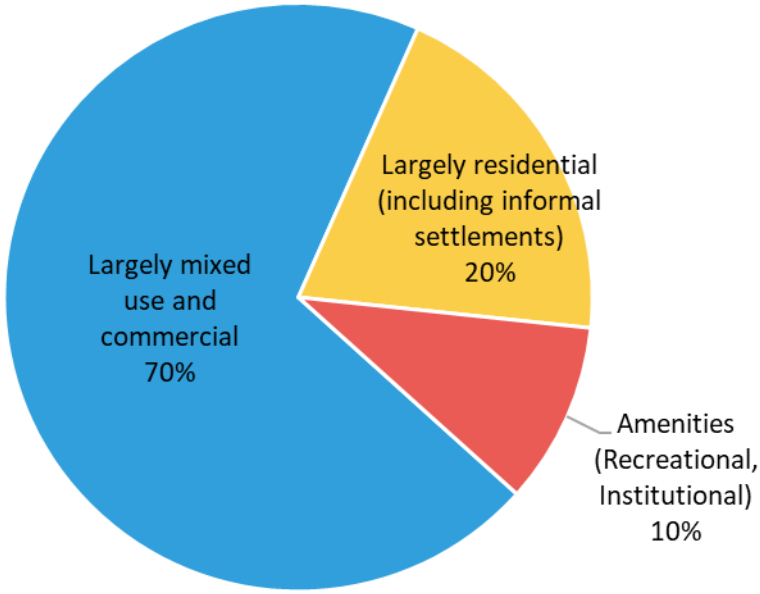

Figure 8: Intersection Blackspots by Adjacent Building Use

Assessment of crash risk typology

For this study, we conducted an assessment of the crash risk typology of Mumbai, using the data from the previously mentioned report by the Mumbai Traffic Police and Vital Strategies. The results of this study are presented in this section.

In Figure 9, we have plotted the number of fatalities by mode for all fatal crashes. The horizontal axis shows the number of crashes involving a particular mode which resulted in a fatality for that mode, while the vertical axis shows the number of crashes that involving the same mode but did not result in a fatality for that mode. This was plotted for about 78% of all the crash records, because the remaining 22% records did not have sufficient information. The travel modes in the bottom right quadrant are considered to be the most vulnerable in crashes, which is the case for pedestrians and motorcycle riders. The users of these modes tend to die in most fatal crashes involving them. On the other hand, the group in the upper left quadrant, that is cars, taxis and other light motor vehicles, tend to be involved in a high proportion of fatal crashes, but their occupants are less likely to die in these crashes.

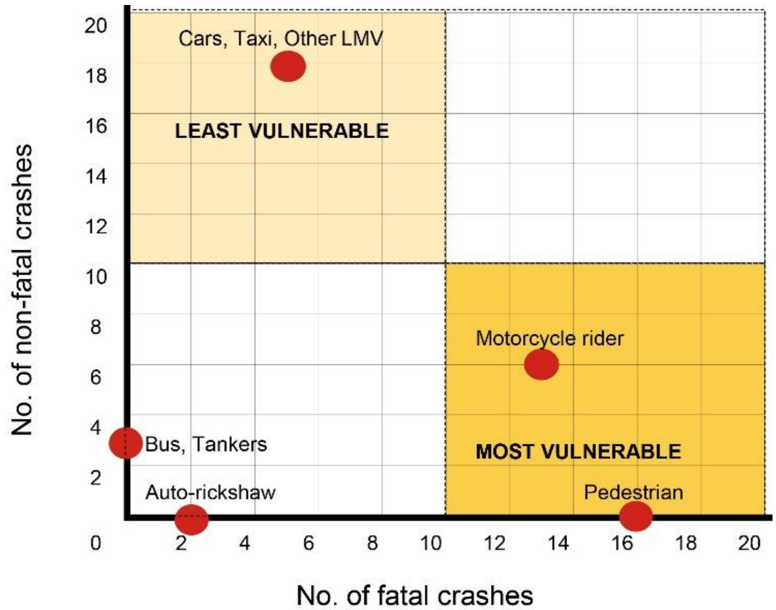

Figure 9: Vulnerability Matrix for Travel Modes

In Figure 10, we have plotted the distribution of road crashes by both the modes involved in the crash. The most prevalent crash type that emerged was that of Light Motor-vehicles (LMVs) with pedestrians, followed by LMVs with motorcycle riders, and LMVs with other LMVs.

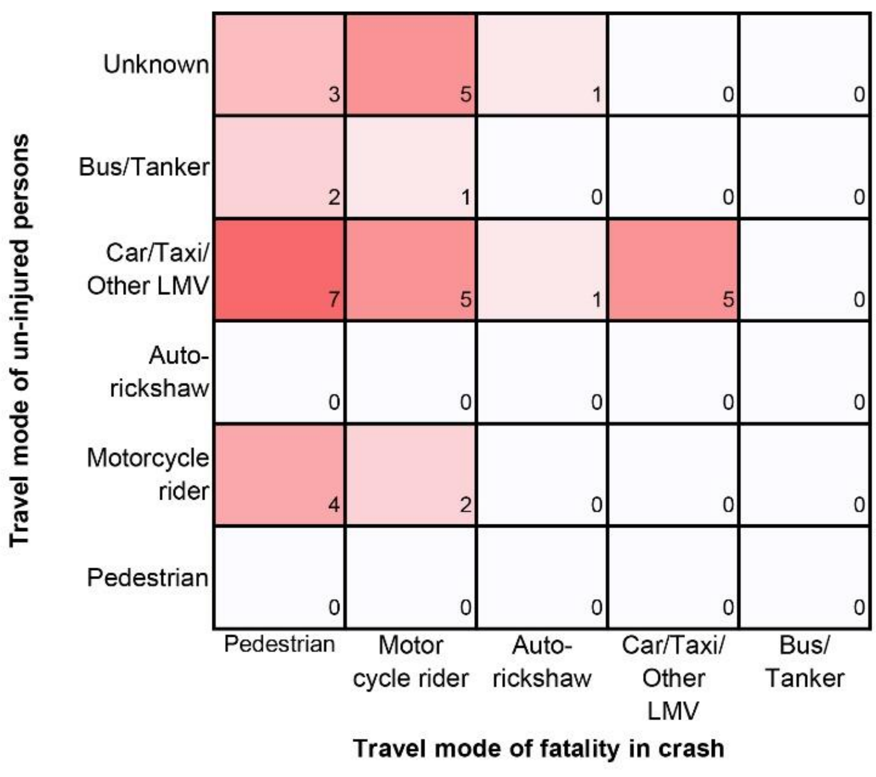

Figure 10: Intersection Fatal Crash Type Distribution

The intersection blackspots were further studied and classified on the basis of intersecting road typologies. The standard definitions of road hierarchy are difficult to apply in the context of Mumbai. For instance, in many cases, it is difficult to distinguish a collector road from a local street, because the same street may provide both functions, that is direct property access and also connecting to a major arterial or highway. Hence, for the purpose of this study, a somewhat modified classification of roads was utilized, and the allocation of each road to a given class was done by using a judicious understanding of the role and function of these roads, with respect to traffic flow and linkages they provide in the city. The modified classification is as follows:

i. Highways: This includes the two major national highways of EEH and WEH, as well as other highways that are part of the inter highway network of the region, such as the Sion-Panvel Expressway

ii. Arterials: This includes major roads that are not highways, but are used predominantly for thoroughfare traffic flows, such as LBS Marg, SV Road, etc. These roads do not strictly follow the standard definition of arterial roads, as they have direct property access, both of residential and commercial in nature.

iii. Sub-arterials: These are similar to the arterials as defined above, but are shorter in length and connect fewer parts of the city. Examples include the Goregaon-Mulund Link Road, Santacruz-Chembur Link Road etc

iv. Collector/Local Streets: These include minor and relatively narrower streets that typically connect the higher order roads to local neighbourhoods..

The intersection typologies were categorised into a diagonal matrix based on the classification of the intersecting roads at these intersections. As there are 4 classes of roads, there will be 10 types of intersection classes, as indicated in Table 1: Intersection Blackspot Typology Matrix with Crashes. The first number shows the number of such intersections that are blackspots, while the number in parenthesis show the number of crashes at such intersections.

Type of Road	**Highways**	**Arterials**	**Sub-arterials**	**Collector/ Local Streets**
Highways	0 (0)	1 (33)	2 (31)	5 (98)
Arterials		3 (45)	1 (10)	5 (73)
Sub-arterials			0 (0)	2 (22)
Collector/ Local Streets				1 (12)

Table 1: Intersection Blackspot Typology Matrix with Crashes. The first number shows the number of such intersections that are blackspots, while the number in parenthesis show the number of crashes at such intersections

The two intersection typologies that emerge as 'high-risk' are Highway with Collector/Local Street; and Arterial with Collector/Local Street. These two typologies apply to 50% of the intersection blackspots and also account for 52% of all crashes.

It should be noted that as per standard road planning principles, a collector/local street must not directly intersect with a Highway. Yet, there are multiple such cases of the same all across Mumbai, and indeed, they are responsible for 5 of the city's major blackspots. This lack of network planning and judicious application of road hierarchy principles in Mumbai means that there are several instances wherein minor local streets directly meet a highway.

When two roads varying so greatly in their traffic-mix, speed and road width intersect with each other, the potential for conflicts is greatly amplified.

In the following section, we have illustrated some examples of intersections in Mumbai that contradict standard design principles, which result in a high safety risk.

Illustration of varying intersection typologies in Mumbai.

Typically, a base for any safe intersection design requires an intersection of equal or near equal order roads, in terms of functional hierarchy. Furthermore, the angle of the intersection should be as close to right-angles as possible, as highly acute or obtuse angles create many safety impediments. In addition, 3 to 4 arm intersections are acceptable for a safe design, and any intersection with 5 or more arms creates complications.

In Mumbai, it is not uncommon to come across intersections that do not fit easily with any standard design template. For instance, there are multiple cases of intersections with 5 or more arms. In other cases, there are intersections with highly skewed angles, in highly built-up areas, making it near-impossible to correct the angle. Furthermore, there are multiple cases of a lower-order local street directly intersecting with a high-order highway. In this section, we have documented three examples that illustrate these issues. In all three cases, the intersections in question are among the blackspot list of Mumbai, that is locations with a high crash-risk.

One such intersection is known as the Worli Naka intersection, located in south-central Mumbai. It is a 6-arm intersection, as shown in Figure 11. This intersection does not mirror the templates one would find in standard street design guidelines. Furthermore, the roads forming this intersection vary greatly in their order and function. The arm extending to the west can be characterised as a local street that ends in a dead-end. While the arm to the east can be characterised as a low-order collector street. The other four arms are more like sub-arterial and arterial roads, and provide connectivity to major areas in the city.

Figure 11: Google Earth satellite image of Worli Naka intersection, accessed in September 2018

On account of the acute angle of this intersection, it is difficult to apply standard design practices. Correction of the angles is near impossible, because the edges are heavily built-up. This particular intersection sees a huge volume of vehicular and pedestrian movement. As is evident in Figure 12, the intersection area is kept very large, in order to accommodate the high throughput of vehicular traffic. This comes at the expense of pedestrian safety, as crossing distance are very long, and there aren't adequate pedestrian refuge areas. A complete safety solution for this intersection will necessarily require concessions on traffic capacity and throughput.

Figure 12: Worli Naka intersection – bird's eye view

Another high-risk intersection in Mumbai is found in the north-central suburbs of the city, and is known as the Priyadarshini circle intersection. The traffic rotary that used to exist at this intersection, (which gives it its name), has since been eliminated to accommodate for the high volume of traffic. (Refer Figure 13.) This intersection sits on the Eastern Express Highway (EEH), the primary arterial highway in the eastern suburbs of Mumbai. It is a 5+5 lane highway and carries a significant volume of thoroughfare traffic.

The two arms in the north, namely VN Purav Marg and Vasantrao Naik Marg can best be described as low-order collector streets. As per road hierarchy protocol, streets of this character must not be allowed to directly connect to a higher-order highway, like EEH. This forces the mixing of slow-moving local traffic with high-speed thoroughfare traffic. Moreover, the angles of this intersection are highly skewed. This makes the angle of entry of vehicles into the intersection very unsafe, as it creates visual blind-spots on the one hand and fails to sufficiently slow down vehicles making turns at the intersection.

Figure 13: Google Earth satellite image of Priyadarshini Circle Intersection, accessed in September 2018

Another problematic intersection in Mumbai is known as Narayan Bodhe Chowk, and is located the northern Mumbai residential suburb of Vikhroli East. This suburb is divided into two parts by the Eastern Express Highway (EEH). The intersection in question is a 4-arm intersection of EEH and a local/collector street known as P Godrej Marg. At this location, the EEH has 5+5 lanes, and a width of approximately 55 meters. In addition, a flyover along EEH traverses this intersection, and carries most of the through traffic. On the other hand, P Godrej is a 2+2 lane road of approximately 14 meters. Its eastern arm connects to a residential colony known as Kannamwar Nagar, while its western arm connects to the local railway station, less than half a kilometre from the intersection.

P Godrej road carries a lot of local traffic, mainly by autorickshaw, motorcycle, bicycle and by foot. This local traffic is forced to intersect with the fast moving traffic of EEH. Even though there is a flyover on EEH, the road and intersection under the flyover have not been suitably calmed. The intersection area is large, with no proper lane alignment and there is a complete lack of any pedestrian infrastructure.

As the collector road leads to a station, there is a fair number of pedestrians crossing the highway to access this road. There are also bus stops on the highway where a number of passengers going to Kannamwar Nagar or the station alight. The lack of appropriate pedestrian infrastructure such as at-grade pedestrian crossings, refuge islands, pedestrian signals forces people to cross the road unprotected. The intersection under the flyover encompasses a large area due to the large highway width. The large intersection is unsafe as it increases the clearance time for pedestrians and vehicles crossing the intersection. Also, the larger turning radii of the kerb corners allow vehicles to make turns at very high speeds.

Figure 14: Google Earth satellite Image of Narayan Bodhe Chowk, accessed in September 2018

Figure 15: Street-level view of P Godrej Marg

Figure 16: Street-level view of Narayan Bodhe Chowk

Conclusion

Within cities, intersections contribute to a disproportionately high share of road crashes, given that they cumulatively take up only a fraction of total road area. As exemplified by the case of Mumbai, there are a multiplicity of design issues which contribute to the high crash risk. The intersection typologies are all very different and hence, the safety issues are not easily addressed by the application of standard street design guidelines, because they encompass conditions that are not always represented by guideline templates.

In order to address the challenges of intersection safety in the urban Indian context, a more pragmatic approach is necessary that considers the optimal solution given unchangeable ground realities. The primary principal of design for these intersections has to be safety first, that is human life must not be compromised no matter what the cost. If the design of these intersections have to viewed through this lens, then it has to be accepted that some concessions to traffic capacity and throughput are unavoidable.

References

[1] Vital Strategies, and Bloomberg Initiative for Global Road Safety. *Crash Data for Mumbai 2014-2017.* Mumbai: Mumbai Traffic Police, 2018.

[2] LEA Associates South Asia Pvt. Ltd., India. *Comprehensive Mobility Plan for Greater Mumbai.* Mumbai: Municipal Corporation of Greater Mumbai, 2016.

[3] Bloomberg Philanthropies Initiative for Global Road Safety, and Mumbai Traffic Police. *Road Safety in Mumbai City: Fatal Road Crashes 2015-2016.* Mumbai: Bloomberg Philanthropies Initiative for Global Road Safety, 2016. Accessed 10 September, 2018. http://delhigreens.com/files/road-safety-in-mumbai-report.pdf.