SAFETY ASSESSMENT FRAMEWORK FOR SIGNALIZED URBAN INTERSECTIONS

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Infrastructure Design and Management

By

Mohd Shabbiruddin Khan Miftahi

18ID60R05

Under the guidance of

Prof. Dr. Bhargab Maitra (IIT Kharagpur)

&

Prof. Dr. Manfred Boltze (TU Darmstadt)

RANBIR AND CHITRA GUPTA SCHOOL OF INFRASTRUCTURE DESIGN AND MANAGEMENT

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

MAY 2020

DECLARATION BY THE STUDENT

I declare that

a. I have done the work contained in this report under the guidance of my supervisors.
b. This work has not been submitted to any other Institute for any degree or diploma.
c. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
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18ID60R05

CERTIFICATE BY THE SUPERVISOR(s)

This is to certify that the project report entitled **"Safety Assessment framework for Signalized Urban Intersections"**, submitted by **Mohd Shabbiruddin Khan Miftahi** (18ID60R05) to the **Indian Institute of Technology Kharagpur**, is a record of bona fide project work carried out by him under our supervision.

13/06/2020

Prof. Bhargab Maitra
IIT Kharagpur

Prof. Manfred Boltze
TU Darmstadt

13/06/2020

Prof. Bhargab Maitra
Head of the School
RCGSIDM
IIT Kharagpur

13/06/2020

External Examiner I

External Examiner II

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Abstract

Urban intersections are very prone to road accidents in India, reporting a high share of serious injuries and fatalities, with the same being true for even signalized intersections in major cities. Rapid population growth and ever-growing personal vehicle ownership have created an imbalance between the demand and supply of transport in urban India. The infrastructure in the country has been unable to keep up with this growing demand, thereby causing problems like congestion, long queue lengths, delays and increasing traffic violations at the intersections. The intersections have not only become inconvenient bottlenecks but also unsafe for all road users. So it has become indispensable to develop an audit based framework that helps in identifying the elements posing the risk of injury, together with the road users who would be hurt in those situations, at these intersections. This framework shall be all-encompassing, taking all road users into account for assessment under mixed traffic conditions, in line with the prevailing state of road traffic in India. The present work is an attempt to develop such a framework for the safety assessment of signalized urban intersections in India, which takes all road users and all accident-causing elements into consideration. Firstly, the major safety aspects and elements of signalized intersections were determined through field observations, literature review, and discussion with experts. This was followed by the development of an Audit questionnaire to not only rate the numerous safety aspects and elements at a signalized intersection but to also identify the various safety deficiencies at the intersection under consideration. To make this audit framework as comprehensive as possible, various Safety aspects have been considered such as the Geometric Design characteristics, Traffic signal elements, Road signs and markings provisions, management-related issues, NMT (Non-motorized Transport) safety elements including pedestrian safety elements, and even the behaviour of road users. The framework was then applied to identify the safety deficiencies and evaluate the safety level of several signalized intersections located along a major urban corridor in Kolkata, India and two major urban corridors in Darmstadt, Germany. Finally, various countermeasures were recommended to fill the safety deficiencies and improve the safety level of these intersections.

Keywords: Signalized Urban intersections, Safety Assessment, Accident Causal factors, Safety Deficiencies, Safety Level.

Contents

List of Figures

List of tables

1 Introduction

1.1. Motivation

Road accidents are one of the major sources of deaths, disabilities, injuries and property damage in the world every year. A study of non-freeway-motor-vehicle crashes in four urban areas of the United States found that 56% of the crashes occurred at intersections *(Retting et al., 1995)*. A review of 1,254 urban crashes in England found that almost 70% occurred at junctions *(Carsten et al., 1989)*. Out of 52645 vehicles involved in fatal crashes in the United States in the year 2017 *(Traffic Safety Facts, 2017)*, 4294 (8.15%) cases were reported at traffic signal intersections and 1440 (2.7%) were reported as traffic signal intersections related. According to the (Road Accidents in India, 2018) report published by the Ministry of Road Transport and Highways (MORTH), a total of 467044 road accidents have been reported by States and Union Territories (UTs) in the calendar year 2018, claiming 151417 lives and causing injuries to 469418 persons. A total of 155069 accidents occurred at intersections which comprise 33.2% per cent of the total accidents recorded in the country. This is because road intersections are points where traffic merges and hence are more prone to accidents in general. So, this has become a serious concern for all the stakeholders involved in road transport, including the citizens and the government. Out of 155069 accidents at road intersections, 40936 (26.4%) accidents took place at intersections which have traffic control measures such as traffic light signals, police control, stop sign and flashing signals/blinkers and the remaining 114133 (73.6%) accidents took place at uncontrolled intersections (Figure 1). This shows the importance and well as the inadequacy of the traffic control mechanism at the intersections. Traffic signal control can reduce conflicts between cyclists, pedestrians, and vehicles travelling in different directions by separating their movements in time, thus maximizing traffic capacity and minimizing the crash risk. The total number of accidents at the signalized intersections still amounted to 13726 (8.85% of total accidents at intersections) in the year 2018, which led to the death of 3325 people. This means that despite all the measures undertaken to control traffic at such intersections, there is still a great scope of improvement to bring the number of accidents down further. Since the majority of intersections in urban areas are signalized nowadays, the same is the focus of this study.

Intersections have not only become inconvenient bottlenecks but also unsafe for all road users, including the cyclists and pedestrians. So it has become indispensable to develop a framework that helps in identifying the elements posing the risk of injury, together with the road users who would be hurt in those situations, at these intersections. Some literature has been established to identify the causal factors of accidents at signalized intersections. *Wang et al. (2006)* conducted a study to predict and describe longitudinal crashes at signalized intersections on the basis of geometry and traffic-related explanatory variables (i.e., viable factors that safety engineers have some control over) through the use of generalized estimating equations (gees). They found that traffic volume, average daily traffic per lane (ADTPL), number of lanes, exclusive left-turn lanes, protected right-turn, and speed limit are some of the factors related to accidents and crashes at intersections. *Zhang et al. (2003)* presented a methodology that quantifies potential conflicts between left-turning vehicles and

opposing through vehicles and pedestrians and developed a model to combine delay and safety to get a comprehensive level-of-service indicator. They concluded that protected left-turn (right turn in countries with left-side traffic) phasing leads to greater delay but lowers the risk of collision at intersections, thereby increasing safety. A study conducted by *Schattler et al. (2004)* showed that if an All Red Clearance Interval (ARI) of adequate length is used, drivers will have a lower probability of being involved in a right-angle crash. *Kumara et al. (2003)* used statistical methods as a novel means of identifying the causal factors affecting accident frequencies at signalized intersection approaches. They found that Traffic Volume, Provision of the exclusive left-turn lane, protected right turn phase, Sight Distance, Number of Signal Phases, and Angle of intersection play a crucial role in the safety level of signalized intersections. *Wong et al. (2007)* used Poisson regression and negative binomial regression to quantify the influence of possible contributory factors on the incidence of killed and severe injury (KSI) crashes and slight injury crashes, respectively, while possible interventions by traffic flow are controlled. They concluded that Traffic Volume, Presence of Bus/tram stop, Jaywalking behaviour by pedestrians and Mixed Traffic conditions are positively associated with crashes at intersections. *Anjan S. Et al. (2015)* examined the crash causative factors of signalized intersections under mixed traffic using advanced statistical models like Hierarchical Poisson regression and logistic regression models. The study showed that ADTPL, Provision of an exclusive left turn, Approach width, presence of Countdown timer, Median width, Visibility at Night, Duration of Green Phase and presence of Lane Markings are some factors influencing safety at the signalized intersections in India. *Xie et al. (2013)* applied Bayesian hierarchical models to identify crash risk factors at both the intersection and the corridor levels. They concluded that limited sight distance at intersections and a large number of signal phases lead to higher crash rates. Similarly, *Ma et al. (2010)* conducted a study to investigate the risk factors associated with severe crash occurrences on arterial roads in Beijing, through the use of generalizing estimating equations model. They found that Traffic Volume, Speed Limit, Presence of Median and Angle of Intersection are some major factors related to the safety of intersections. *Koh et al. (2014)* conducted a study on the safety evaluation of pedestrian behaviour and violations at signalised pedestrian crossings and found that waiting time was a factor that was found to influence violations by pedestrians. Further, Pedestrian countdown timers were found to increase the crossing speeds of pedestrians. In the study conducted by *Brosseau et al. (2013)* on pedestrian violations and dangerous crossings at signalized intersections and their relationship with factors such as maximum waiting time, time of arrival, and the presence of a pedestrian signal, it was found that the presence of pedestrian signals, pedestrian countdown timers, waiting time and clearing time were found to affect the safety of pedestrians at signalized intersections. *Lee et al. (2005)* conducted a comprehensive analysis of vehicle-pedestrian crashes at intersections in Florida. They also found that traffic volume and visibility at night are significant factors that affect the safety of intersections.

Safety assessment is needed to prioritize the safety improvement works in developing countries because generally there is a shortage of funds available to upgrade all the intersection. Safety assessment of intersection is often carried out using crash data *(Poch et al.,1996; Kim et al., 2009)*. However, in the context of emerging countries such as India, safety assessment of intersection is challenging as reliable crash data for intersections are generally unavailable, mostly because generally crash data for intersections are not recorded. The guidelines for road safety published by various agencies across the globe like IRC and FHWA for auditing road safety identifying the Safety

deficiencies are very helpful in this regard, however, they are still lacking in certain safety aspects. So the aim of this study is to develop a safety assessment framework that can be applied to identify various safety Deficiencies such as geometric design deficiencies, traffic control deficiencies, Traffic signal deficiencies, road signs and marking deficiencies, management deficiencies, road user behaviour aspects, and evaluate the safety of Signalized Intersections in the absence of crash data, thereby, accentuating the infrastructure deficiencies and highlighting the respective countermeasures and policy-level interventions that should be adopted, in order to make the intersections safer and more efficient for all road users.

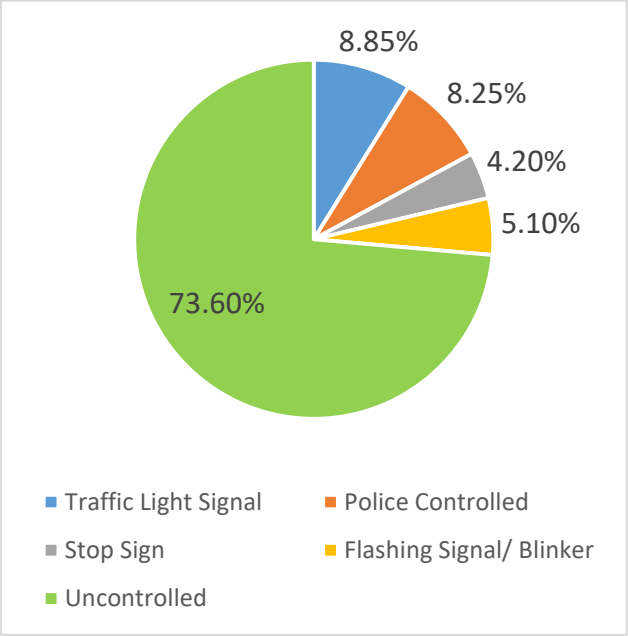

Figure 1 Percentage distribution of accidents at various intersection types in India, 2018

1.2. Study Objectives

The broad objective of this study is to develop a framework for the safety assessment of signalized urban intersections as a proactive approach under mixed traffic conditions, giving due consideration to different road users and related accident causal factors. To achieve the above-mentioned objective, the scope of work is outlined as the following:

- Review the existing practices and standards to ensure safety at signalized intersections.
- Identify the causal factors/elements that lead to unsafe acts at signalized intersections by means of field observations and literature review.
- Develop a framework to assess the safety level of intersections.
- Conduct audit at several signalized intersections in varying urban environments to identify their respective safety deficiencies.

- Recommend several countermeasures and policy-level interventions to improve intersection safety performance.
- Perform a comparison of the safety level of signalized intersections from different urban environments.

This study is inclusive of different road users including Non-motorised Transport users like pedestrians, cyclists, rickshaws, wheelchairs, strollers etc. but it would be only applicable to intersections with a simple layout. Complex road intersections with grade separation would require further study and modifications for the framework to be applicable. Both peak- and lean-hour traffic conditions have been considered to make the study as comprehensive as possible.

2 Methodology

A methodology to assess and improve the safety level of the at-grade signalized intersection is discussed in this section. It includes Identification of accident causing factors in and around the at-grade signalized intersection, development of a model to assess the safety level of the at-grade signalised intersection, field data collection and database generation, prioritization of signalized intersection of its improvement and identification of safety deficiencies in and around the at-grade signalized intersection and recommending measures for improving its safety level. Figure 2 gives the overall structure of the methodology:

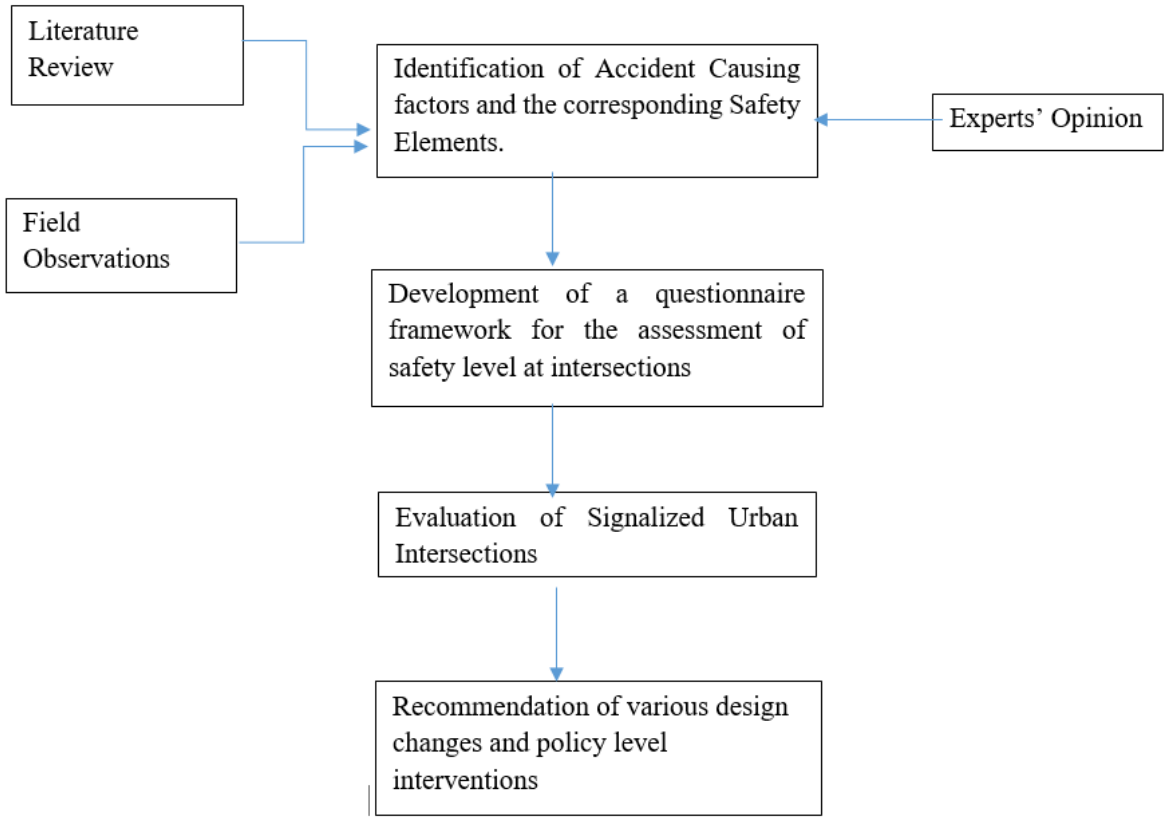

Figure 2 Methodology

2.1. Identification of Accident Causing factors

To make a signalized intersection safe, all the factors that lead to accidents at that intersection should be identified and corresponding safety elements must be introduced to eliminate them. To identify these factors and their corresponding safety elements, a detailed literature review was carried out which included various IRC codes, FHWA codes and work by various authors discussed in the literature review section. The opinion of several experts and field observations were also considered in the identification of the safety elements.

2.2. Design of Framework

These safety elements were then categorized under various Safety aspects like geometric design characteristics, traffic signal characteristics, road signs attributes, road marking attributes, management issues, pedestrian safety considerations, NMT safety considerations and road user

behaviour. This was followed by the design of a questionnaire survey that could be applied to identify the safety deficiencies at a signalized intersection and evaluate its safety level.

2.3. Evaluation of Signalized Urban Intersections

Using this framework various intersections in India and Germany were evaluated by experts. 5 Intersections in Kolkata at the Eastern Metropolitan Bypass and 10 intersections in Darmstadt on the Rheinstrasse and KasinoStrasse Corridors were selected for this work. The reason these corridors were selected was because of the high traffic volume and crash rates there. Every intersection was evaluated twice, once during peak day and once during the off-peak night.

2.4. Identification of Safety Deficiencies and Countermeasures

Finally, the data collected was qualitatively evaluated to identify the safety deficiencies at these intersections and make several design change recommendations and policy-level interventions with the aim of improving the safety level of these intersections. These recommendations are based on inputs by the group of experts who did the evaluation of these intersections. The Signalized intersections in India and Germany were also compared to find the difference in the safety level of intersections in these two countries.

3 Identification of Causal Factors

Many actions performed by various Road users, may result in vehicle-vehicle or vehicle-pedestrian conflicts. For instance, a vehicle crossing the intersection during the Red signal is an unsafe act that can lead to conflict with the cross-traffic or pedestrians and cause accidents at signalized intersections. But there are multiple factors that can lead to this unsafe act, including the Red phase being too long for the motorists, Traffic signal being not visible etc. These factors which may contribute to this unsafe act are called the Accident Causal Factors. These factors are always dictated by the presence or absence of certain elements at the intersection. These are referred herein as Safety Elements. So the length of the Red phase and Visibility of the Traffic Signal are important safety elements that contribute to the safety level of signalized intersections. These Safety Elements are important components of the Traffic Signal elements, which is an important Safety Aspect of any intersection. Many such safety elements were identified in this study by means of literature review, field observations and experts' opinion and categorized under the appropriate Safety Aspect. The Traffic Safety aspects have been identified as Geometric Design Characteristics, Traffic Signal Elements, Road Sign elements, Road Marking elements, Management Issues, Pedestrian Safety elements, Non-Motorized Transport (excluding pedestrians) Safety Elements and Road User Behaviour. These safety elements are discussed in detail in the following sub-sections:

3.1. Geometric Design Characteristics

Geometric design of an intersection refers to the functional layout of travel lanes, sidewalks, crosswalks, cycle lanes, and transit stops in both horizontal and vertical dimensions. It profoundly influences roadway safety and operational performance for all road users *(Chandler et al., 2013)*. The major geometric design components that contribute to the safety of signalized intersections have been identified as: i) adequacy of the junction for all allowable vehicular movements and for all types of vehicles, ii) clarity in the route through the intersection to the approaching motorist, so that the junction type, layout and the priority rules can be recognized by approaching motorists well in advance, iii) provision and alignment of channelizers and traffic islands at appropriate locations to improve junction conspicuity and ensure orderly flow of traffic *(IRC: SP:88-2010; McGill et al., 2005)*, iv) presence and sufficiency of the storage area of left turning and right turning lanes lane at the intersection, so that motorists don't have to undertake dangerous manoeuvres and face difficulty when it is their turn to cross the intersection *(Wang et al., 2006; Kumara et al. 2003; Anjana et al., 2015)*, v) sufficiency of the roadway width and capacity at the exit to ensure smooth movement of the entering vehicles, vi) provision and alignment of the median divider for two-way traffic at the intersection, so that vehicles do not get into head-on conflicts by running into the wrong side *(Ma et al., 2010)* vii) adequate intersection sight distance and line of sight to the conflicting traffic, pedestrians and traffic control elements from the stop line, so as to enable motorists to perceive and react to their presence in time *(Kumara et al., 2003; Xie et al., 2013; Chandler et al., 2013; IRC:SP:88-2010)*, viii) adequate and appropriate turning radius for right turning and left-turning vehicles at the intersection approach under consideration, so as to prevent motorists from dangerous manoeuvres and conflicts while turning *(Chandler et al., 2013)*, ix) presence and location of the bus stop at the intersection in terms of safety and efficiency *(IRC:SP:88-2010; Wong et al., 2007)*, x) segregation of the bus stop from the traffic lanes, xi) adequacy of the Bus stop design in terms of capacity and frequency of bus arrival/departure, so that buses are not forced to stop at the intersection *(IRC:SP:88-2010)* and xii) adequacy of speed management provisions like speed breakers, speed limit signs, grade etc. to prevent motorists from over speeding *(Wang et al., 2006; Ma et al., 2010).*

3.2. Traffic Signal Elements

One of the major causes of crashes at signalized intersections is the violation of the traffic signal at the intersection. So proper design and application of the traffic signal is an important component in improving the safety and efficiency of the intersections. The most significant Traffic Signal elements that influence the safety of signalized intersections have been broadly identified as follows: i) visibility of the Traffic signal so that motorists are able to respond to it on time, ii) clarity with which the signals indicate which movements are allowed at one time, and iii) appropriate location of the signals for competing phases so that they are only visible to traffic for which they are intended, in order to avoid confusion in the motorists about the right signal for them *(IRC:SP:88-2010),* iv) sufficient provision of green time for the through traffic stream emerging from the intersection leg under consideration, to prevent the urge to commit red-light violation in drivers *(Anjana et al., 2015),* v) efficient utilization of the green time at the leg of the intersection under consideration, so that the other traffic streams are not prompted to jump the red light and cross the intersection during such idle green time, vi) adequacy of the amber time in the signal cycle, so that motorists are warned in advance about the signal change and have sufficient time to make the right decision (whether to stop or cross the intersection), vii) sufficient provision of inter-green time to clear the intersection of the late entering and late exiting vehicles *(Schattler et al., 2004),* viii) a protected left turn and right turn traffic signal to prevent sideswipe with the cross-traffic *(Wang et al., 2006; Zhang et al., 2003; Kumara et al., 2003)* and ix) adequacy of the timing of the left and right turn phases *(Anjana et al., 2015).* All these safety measures ensure that the motorists are not prompted to commit stop line violation, red light violation and engage in dangerous manoeuvres (like stopping during the green time, trying to overtake the leading vehicles to cross the intersection before the onset of the red signal, etc.) resulting into conflicts.

3.3. Road Sign elements

Road signs are installed to provide valuable information to various road users as they represent the rules that keep them safe and help communicate messages to drivers and pedestrians to maintain order and reduce accidents. Their usage at roads and intersections depends on the circumstances and requirements. Neglecting them can lead to accidents and hence they have been considered as important safety elements in this framework. Various Road sign elements identified to measure the safety level of intersections are: i) provision of proper and adequate road signs (regulatory, warning and informational signs) in accordance with the standards to avoid confusion while ensuring that sign messages are compatible with the messages of other devices like line markings *(IRC:SP:88-2010; McGill et al., 2005),* ii) appropriate spacing and placement of the road signs, such that, too many signs are not be placed close to each other and they do not affect the line of sight for drivers and pedestrians, iii) visibility of road signs for the intended road users especially at night when the visibility is low, iv) appropriate signage at locations along the junction layout to assist drivers and satisfy the needs of the unfamiliar driver, and v) provision, visibility and adequacy of the intersection sign, advance direction sign and distance information sign on the approach for the road users *(IRC:SP:88-2010).*

3.4. Road Marking elements

Road markings are provided to guide and control traffic on roads and intersections. They ensure the safe, smooth and harmonious flow of traffic by supplementing the function of traffic signs. Serving as a psychological barrier and signifying the delineation of traffic path and its lateral clearance from traffic hazards for the safe movement of traffic, are some characteristics of the road markings. The significant road marking elements that contribute to the safety of signalized intersections have been

identified as: i) visibility of the stop line for the approaching motorist, so that stop line violation (crossing the stop line when the signal is red) can be avoided, ii) appropriate location of the stop line from the intersection so that motorists are not prompted to stop beyond the stop line when it is too far from the intersection *(IRC:SP:88-2010),* iii) adequacy and visibility of longitudinal markings (like lane markings, median markings, edge lines, bus lane markings, centre line markings etc.) at the intersection approaches to delineate lanes and lane use, iv) adequacy and visibility of the intersection markings other than crossings and stop lines (like continuity lines, directional arrows, give way, box markings etc.) marked on the pavement to convey important guidance, warnings, and regulatory lane-use, v) adequacy and visibility of the object markings (like kerb markings, island markings etc.) at the intersection and its approaches to warn the driver about their presence, especially at night time when visibility is low *(IRC:35-1997),* vi) provisions to emphasize the delineation of merging and diverging areas with the help of delineators and chevron signs, vii) adequate provision and visibility of 'Hazard markers' at the approach end of islands, medians, other obstructions and upon lane/median transition, so that collisions with them are avoided when the visibility is low *(IRC:SP:88-2010).*

3.5. Management Issues

In general, in developing countries such as India, management issues are very common, and a major source of concern for most intersections. Even if the intersection design is as per requirements, in several cases, the management related deficiencies make the intersection unsafe. These issues are either enforcement-related or maintenance-related. The major management issues considered in this study can be summarized as follows: i) condition of queue spillback from the downstream intersection preventing the entering vehicles from clearing the intersection, ii) sufficiency of pavement surface grip of the approach so that the skidding of vehicles while stopping is avoided, iii) Clearance of the intersection functional/conflict area from local blockage (Bus stop, Bus not stopping at the designated lane, parking, encroachment), unwarranted stationary obstacles (like large potholes, open manholes etc.), and unwarranted movable obstacles like handcarts, animals etc. so as to prevent the vehicles from deviating from the delineated travel paths and getting into conflicts, iv) regulation of the movement of Non-Motorized Transport vehicles (like bicycles, rickshaws etc.) since they are often involved in conflicts with motorized vehicles due to the speed differential between them while moving on the same carriageway, and v) overall illumination condition at the intersection, so that all road users are visible to each other *(IRC:SP:88-2010; Anjana et al., 2015; Lee et al., 2005).*

3.6. Pedestrian safety elements

Pedestrians are amongst the most vulnerable road users, especially in emerging countries like India where very little attention is paid towards their safety by the road designers and users alike. Provision of adequate facilities and road furniture for pedestrians is rarely seen. In the year 2018, 78974 (16.91%) accidents involved Vehicle to pedestrian collision in India out of a total of 467044 accidents which resulted in the death of 24861 pedestrians *(Road Accidents in India, 2018)*. Thus, special considerations have been given to the safety of pedestrians in the designing of this framework. The significant pedestrian safety elements identified are: i) adequacy of the sidewalk facility in terms of width/capacity, so that pedestrians are not forced to walk on the carriageway, ii) clearance of the sidewalk from encroachment to the pedestrians, iii) condition of the footpath (in terms of pavement condition and clear of trash, debris, snow etc.) for pedestrian use, iv) appropriateness of the pedestrian facilities in providing barrier-free access to people with disabilities, baby strollers etc. *(Chandler et al., 2013),* v) adequacy of the capacity of waiting area for the

designated bus stop/taxi stop etc., if the designated stop is present at/near the intersection block so that people are not forced to stand on the carriageway, vi) sufficient illumination at the sidewalk/ designated bus/taxi stop waiting area so as to instil a sense of safety and security in the pedestrians at night, thereby encouraging them to use these facilities *(IRC:SP:88-2010; Anjana et al., 2015; Lee et al., 2005),* vii) proper connection of the sidewalks with the crossing facilities to ensure their utility and prevent pedestrians from jaywalking, viii) accessibility of the crossing facility from both ends, ix) clearance of the crossing facility from encroachment and available to the pedestrians for easy use, x) condition and maintenance of the crossing facility, xi) adequacy of the width/capacity of the crossing facility to ensure adequate opportunity for crossing, xii) proper illumination at the crossing facility so that it is visible to pedestrian and motorists *(IRC:SP:88-2010; Anjana et al., 2015; Lee et al., 2005),* xiii) provision, position and visibility of the pedestrian signals so that they are easy to spot for the pedestrians, xiv) provision of protected crossing movements for pedestrians to prevent conflicts with through traffic movements, right turn traffic movements and left-turn traffic movements *(Brosseau et al., 2013),* xv) provision, visibility and adequacy of the pedestrian countdown timer to aid the pedestrians in crossing/waiting decisions, xvi) appropriate and bearable waiting time for the pedestrians at the crossing, and xvii) adequacy of the Clearing time for the pedestrians so that they have sufficient time to safely cross the road *(Koh et al., 2014; Brosseau et al., 2013).*

3.7. Non-motorized Vehicle (NMV) safety elements

Non-motorized vehicles are modes of transport that are human/ animal powered such as Bicycle, and variants such as small-wheeled Transport (skates, skateboards, push scooters and hand carts), Cycle Rickshaws and Wheelchairs. The users of these vehicles are also amongst the most vulnerable road users. As per MORTH 22248 (4.76 %) accidents in India involved Vehicle to non-motorized vehicle collision out of a total of 467044 accidents, which resulted in the death of 8753 persons (Road Accidents in India, 2018). As such special importance has also been given to the safety of NMV users in this study. Various safety elements considered are: i) degree to which the crossing movements pf NMVs are protected from conflicting traffic movements, ii) provision, adequacy and visibility of road markings/signs provided for NMV users to make proper manoeuvres on the intersection, iii) adequacy of the green time for the NMV users so that they are also able to cross the intersection along with motorised vehicles, iv) adequacy of the clearance time for NMV users to ensure that the intersection is clear of late entering/exiting NMVs when green time for the conflicting traffic starts, and v) safety and adequacy of the crossing facilities for NMT users.

3.8. Road User Behaviour Characteristics

In emerging countries like India, it is frequently observed that road users are seldom disciplined and non-compliance with the traffic rules and regulations is a major concern. Display of unruly behaviour on roads and intersections by the road users can lead to serious accidents. As such road user behaviour has also been considered as an important safety element in this framework. Major road user behaviour characteristics contributing to the safety of signalized intersections have been identified as: i) compliance of the behaviour of the motorists in terms of not crossing the stop line during red signal, ii) compliance of the driver against stopping during the green time (excluding PT/IPT modes), iii) compliance of the drivers in terms of not making dangerous manoeuvres (other than stopping during the green time such as trying to overtake others, taking U-turns when not permitted etc.), iv) compliance of IPT/PT drivers in terms of not making unauthorised stops at the intersection, v) compliance of the drivers in terms of not speeding up to clear the intersection during the green time, vi) compliance of the drivers in terms of not stopping suddenly when the signal turns

to red again, vii) compliance of the pedestrians in terms of using the designated crossing facilities, viii) compliance of pedestrians in terms of using the sidewalk/designated PT/IPT stopping facility *(Koh et al., 2014; Brosseau et al., 2013)*, and ix) compliance of NMV users in terms of following the traffic rules at the intersection.

3.9. IRC Guidelines considered

Several IRC guidelines were also referred to make the safety framework as comprehensive as possible. They are as shown in table 2 below.

Table 1 List of all IRC guidelines referred to draft the framework

IRC Guidelines	Description
IRC SP41-1994	Gives guidelines for the design of At-Grade signalized Intersection in Urban Areas. Guidelines include types of intersection, types of conflicts and geometric design for intersections.
IRC 103-1988	Gives guidelines for the design of pedestrian facility with includes footpath with guard rails, at-grade and grade separated cross walk.
IRC 35-1997	This code gives the pavement markings guidelines in and around at-grade signalized intersection.
IRC SP88-2010	This guideline gives the basic idea about Road Safety Audit which is needed to conduct expert rating and also gives some idea about general safety deficiencies which are found in and around at-grade signalized intersection.
IRC 67-2012	This guideline talks about different road signs present in and around at-grade signalized intersection and its warrants for installation
IRC 93-1985	This guideline gives an idea about design and installation of road traffic signals with includes all-red time, clearance interval, minimum traffic signal visibility distance, pedestrian signal and signal coordination.

IRC SP41-1994 was referred to get some knowledge on the Geometric Design of Signalized Intersections and was very instrumental in designing the first section of the Framework involving ‘Geometric Design characteristics’. IRC 103-1988 helped in understanding the guidelines followed while designing of various pedestrian facilities at intersections and was very useful in designing of

the sixth section of the framework called ‘Pedestrian Safety’. IRC 35-1997 helped in understanding various aspects related to road markings and was referred to design the fourth section of the Framework called ‘Road Markings’. IRC 67-2012 was studied in order to get knowledge of the correct usage and placement of various road signs recommended in different situations. It helped tremendously in the design of the third section of the framework named ‘Road Signs’. IRC 93-1985 was studied in depth to understand various nuances involved in the design of Traffic signals and was very instrumental in the design of the second section of the framework called ‘Traffic Signals’. IRC SP88-2010 is the document which is most closely related to the purpose of this work and was the fundamental literature which was referred to get an understanding of how Road Safety Audit is implemented and what are the various safety-related questions that an auditor needs to ask to find the safety deficiencies of an intersection. Other than the abovementioned IRC codes some FWHA codes were also used in fine-tuning the framework and have been cited in the earlier sections.

4 Study Area and Database

4.1. Study Area

Signalized Intersections on the Eastern Metropolitan Bypass in Kolkata city was selected for this study. A total of 5 intersections from Patuli intersection to Ultadanga flyover have been studied. Kolkata city was selected for study because it is among the largest cities of India which is recording a large number of accidents. These are: Ajay Nagar, Hiland Park, Mukundapur, Ruby and Patuli intersections. The corridor studied is shown in Figure 3.

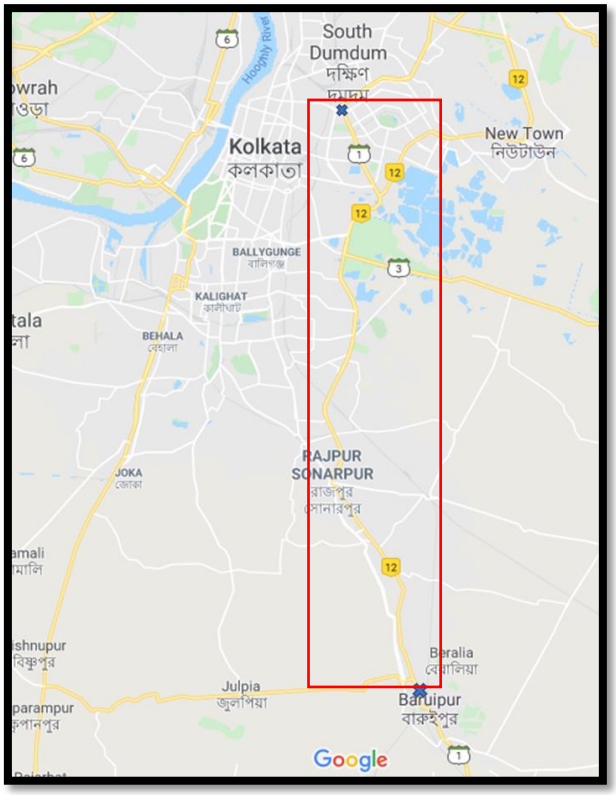

Figure 2 The Eastern Metropolitan corridor in Kolkata considered in the study

In Germany, ten intersections in the city of Darmstadt were studied under this work. These signalized intersections lie on two very important road corridors viz. Rhein strasse and Kasino Strasse-Neckar Strasse. The intersections studied have been labelled as A1, A2, A3, A4, A12, A13, A22, A23, A24 and A45. The Corridors are shown in Figure 4.

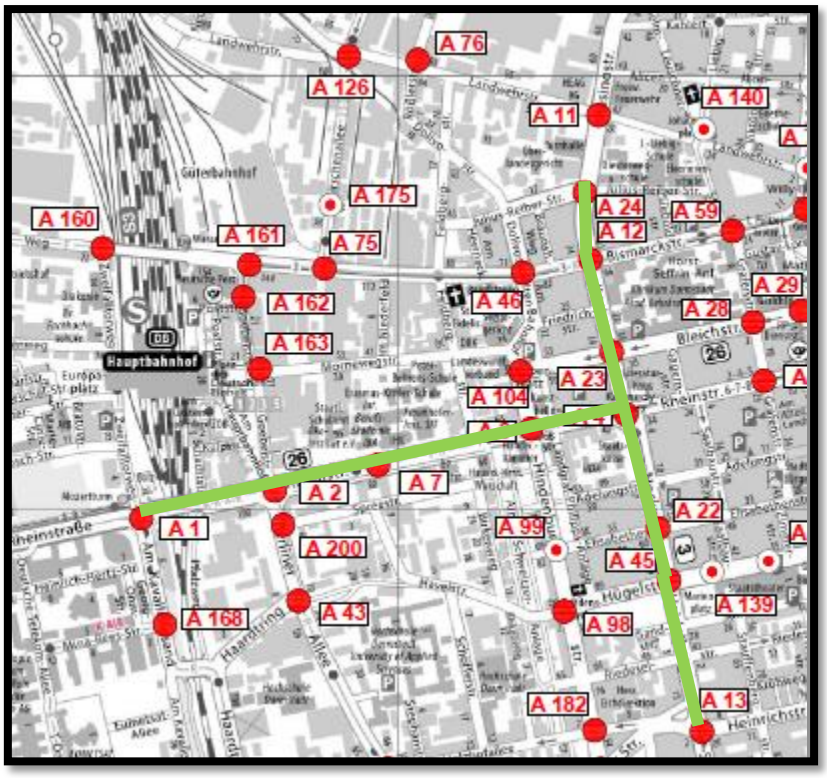

Figure 3 Corridors considered for the study in Darmstadt, Germany

4.2. Database

To assess the safety levels of signalized intersections of the corridors mentioned in Section 4.1 and 4.2, team of five experts visited the sites in India to rate various safety aspects and safety elements. The various safety aspects considered in this study are geometric design characteristics, traffic signal characteristics, road sign attributes, road marking attributes, management issues, pedestrian safety considerations, NMT safety considerations and road user behaviour. The related safety elements have been discussed in Section 3. The final questionnaire has been provided in the Appendix section of this report. While, in Germany due to the lack of resources, the data was collected by the author himself. In total 15 intersections have been studied, 5 in Kolkata and 10 in Darmstadt. Data was collected for every intersection twice, once for peak traffic during day time and once for off-peak night. This was done because the traffic volume and composition changes drastically at the intersections during night. Not to mention that illumination and visibility also plays major role in the safety performance during night time. From the data collected, it was quite obvious that the intersections in Germany are quite safe compared to intersections in India.

A qualitative descriptive analysis of the data collected from the signalized intersections was conducted to identified the various safety deficiencies and make various design change recommendations and policy level interventions. The overall average safety level of the intersections on scale of 1 to 5 (1 being the worst and 5 being the best), graded by the experts on the basis of field observations and field data collection are shown in the Table 3. These scores are the average of the safety levels assigned by the experts in the framework during the peak day hours when the traffic volume is high and the off-peak night hours when it is low.

Table 2 Average scores of overall safety of intersections studied in Kolkata

Intersection in Kolkata	Average score of the overall safety
Ajay Nagar	2.9
Hiland Park	2.4
Mukundapur	3.1
Patuli	3.6
Ruby	3.1

Table 3 Average scores of overall safety of intersections studied in Darmstadt

Intersection in Darmstadt	Average score of the overall safety
A1- Rheinstrasse/ Kavalleriesand	4.0
A2- Rheinstrasse/Berliner Alle	4.5
A3- RheinStrasse/ HindenbergStrasse	3.5
A4- Rheinstrasse/Neckarstrasse/Kasinostrasse	4.0
A12- Kasinostrasse/Bismarckstrasse	3.5
A13- Heidelbergerstrasse/ Heinrichstrasse	3.5
A22- Neckarstrasse/Elizabethenstrasse	3.0
A23- Kasinostrasse/ Bleichstrasse	4.0
A24- Kasinostrasse/ Julius-Reiber-Strasse	4.0
A45- Neckarstrasse/Hugelstrasse	4.0

5 Safety Deficiencies and Countermeasures

During expert survey, safety deficiencies for each study intersection were found out and various countermeasures were suggested to deal with them as discussed in the following sections:

5.1. Signalized intersections in Kolkata, India

5.1.1. Ajay Nagar Junction

A) Safety Deficiencies

- From the Northern, Eastern and southern legs of the intersection, sight distance to the cross traffic is not available with the presence of trees and traffic police booth obstructing view.
- Left Turn Channelization is absent on all legs of the intersection (Figure 6).
- The storage lane for the right turn on the Northern leg is not sufficient (Figure 8).
- On the Western leg, Bus stop has been provided on the far-side and very close to the approach, which is very unsafe & inefficient. On the Northern Leg, no Bus stop has been provided (Figure 7).
- Proper road signs have not been provided to guide the road users (Figure 9).
- On the Eastern leg, the stop line provided is too far from the intersection and is missing along with Stop line at the Western leg.
- Longitudinal Markings are absent on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. have not been provided at the intersection.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators have not been provided.
- Sidewalk is absent on the Eastern leg and the sidewalk on the western leg is not connected properly with the intersection. Sidewalks have not been designed to ensure barrier free access to Non-Motorized Transportation modes.
- Sidewalks and crossings are not connected properly.
- Bus stops have not illuminated properly.
- Pedestrian signal is absent on the Eastern leg and pedestrian countdown timers are missing on all legs.
- No Road markings and signs provided to aid Non –Motorized Transportation modes.
- Unruly behaviour by road users, especially IPT and two wheeler users (Figure 10).

B) Countermeasures

- From the Northern, Eastern and southern legs of the intersection, obstruction to the sight distance to the cross traffic like the trees and traffic police should be removed.
- Proper channelization should be done at the intersection, especially for the left turns.

- The storage lane for the right turn on the Northern leg should be widened.
- Proper, well designed Bus stops should be provided on the Northern and Western legs.
- Adequate road signs to aid traffic should be provided.
- On the Eastern leg, the stop line should be moved close to the intersection. Stop line and pedestrian crossing should be provided at the Western leg.
- Longitudinal markings should be provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. should be provided to guide the flow of traffic.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators should be provided.
- Sidewalk should be provided on the Eastern leg and the sidewalk on the western leg should be properly connected with the intersection. All sidewalks should be redesigned to ensure barrier free access to Non-Motorized Transportation modes.
- Sidewalks and crossings should be connected properly.
- Bus stops should be illuminated properly.
- Pedestrian signal should be provided on the Eastern leg and pedestrian countdown timers should be provided on all legs.
- Road markings and signs should be provided to also aid Non –Motorized Transportation modes.
- Proper enforcement of Traffic rules is needed prevent unruly behaviour by road users, especially IPT and two wheeler users.

Figure 4 Junction layout of Ajay Nagar intersection (Source: Google Maps)

Figure 5 Make shift arrangement for channelization

Figure 6 Absence of proper Bus stop and shelter

Figure 7 Absence of right turn storage lane

Figure 8 Improper placement of no right turn sign

Figure 9 Stop Line violation by two-wheelers

5.1.2. Hiland Park Junction

A) Safety Deficiencies

- Metro column causes a change in the alignment of the Eastern Metropolitan bypass road. (Figure 12).
- The Northern leg changes width from 4 lanes to 2 lanes leading to congestion and unruly behaviour.
- No Bus stop has been provided at the Southern Leg.
- Multiple signal heads have been provided which leads to confusion amongst motorists.
- Inter-green time for the Western Leg is insufficient.
- Proper and Adequate road signs have not been provided (Figure 13).
- Longitudinal markings have not been provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. have not been provided on the intersection (Figure 14).
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators are absent.
- Sidewalk has not been provided on every leg. (Figure 17)
- Crossing Facility has not been provided on the Western leg. (Figure 16)
- Pedestrian signal and countdown timer have not been provided on the Western leg. (Figure 15)
- No Road markings and signs have been provided to aid Non –Motorized Transportation modes.
- Unruly behaviour by road users has been observed. (Figure 18, 19, 20)

B) Countermeasures

- Metro column that causes change in the alignment of the Eastern Metropolitan bypass road should be properly delineated with the help of markings and delineators.
- Proper delineating and merging signs should be provided on the Northern leg to deal with the change in the lane width.
- Bus stop should be provided at far side of the Southern Leg.
- Multiple signal heads provided should be removed leaving only the primary signals since it leads to confusion amongst motorists.

- Inter-green time for the Western Leg should be increased.
- Adequate road signs to aid traffic should be provided.
- Longitudinal markings should be provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. should be provided to guide the flow of traffic.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators should be provided.
- Proper Sidewalks should be provided on all legs with proper barrier free access.
- Crossing Facility should be provided on the Western leg.
- Pedestrian signal and countdown timer should be also provided on the Western leg.
- Road markings and signs should be provided to also aid Non –Motorized Transportation modes.
- Proper enforcement of Traffic rules is needed prevent unruly behaviour by road users.

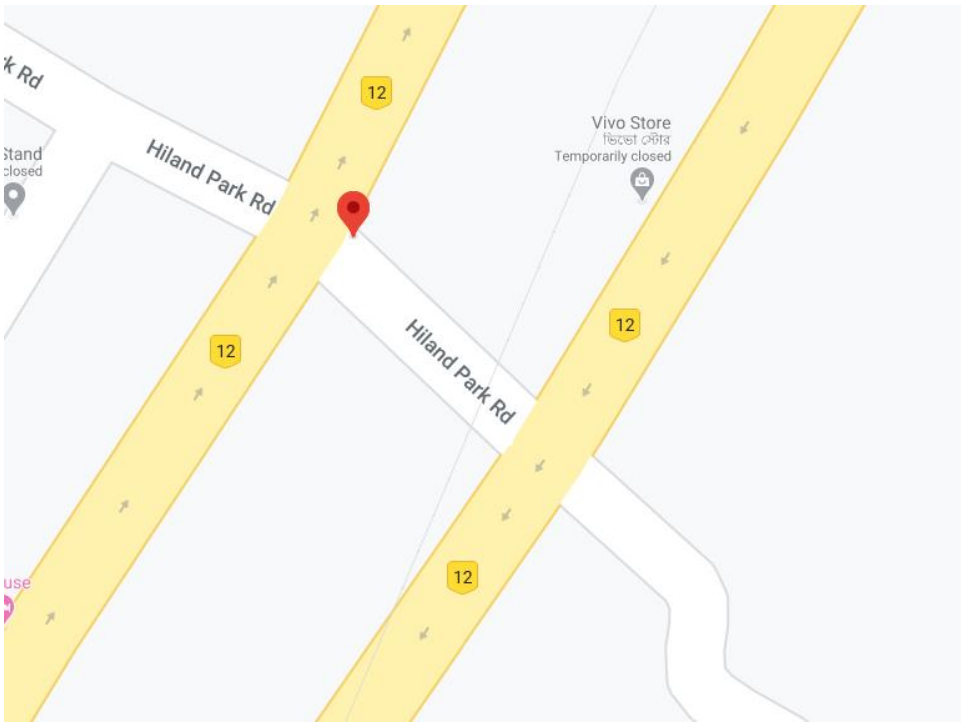

Figure 10 Junction layout of Hiland Park Intersection (Source: Google Maps)

Figure 11 Bottleneck created due to the Metro column

Figure 12 Improper placement of the no U-turn Sign

Figure 13 Intersection lines missing

Figure 14 Pedestrian signals and Timers missing

Figure 15 Crossing Facility Missing

Figure 16 Absence of pedestrian facilities promoting Jaywalking

Figure 17 Vehicle speeding up to cross the intersection

Figure 18 Stop Line violation by road users

Figure 19 Pedestrian not using sidewalk facility

5.1.3. Mukundapur Intersection

A) Safety Deficiencies

- On the Northern Leg, high volume of U-turn traffic occupies the right most lane creating hindrance to the through traffic.
- Some shrubs are blocking the line of sight of the cross traffic from the Northern leg.
- Bus stop on the Northern leg is very close to the intersection and has no shelter. (Figure 22)
- On the major road, a separate bus lane is provided but traffic interferes.
- The signals show lack of signal coordination and the timers are improper.
- The left turn on the Northern leg is permitted.
- On the Northern leg, U-turn traffic interferes with the right turning traffic of the Eastern and Southern approaches.
- Road signs are inadequate to aid traffic.
- Longitudinal markings are absent on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. have not been provided on the intersection.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators have not been provided.
- There is no warming sign/marking for the road users against the canal on both Northern and Eastern approaches. (Figure 23)
- Central rotary leading to queue spillback due to the vehicles standing near it violating the signal. (Figure 26)
- Barricades placed on random locations on the road and the IPT vehicles stopping at the intersection and leading to conflicts. (Figure 24)
- On the southern leg, sidewalk is available but not visible since it is beyond the kerb/Decorative islands. On the Eastern Leg Sidewalk is present but not connected to the intersection and crossings. Illumination at the sidewalks is also poor at night. Proper Crossing facilities are absent on the Northern and Eastern legs.
- No Road markings and signs have been provided to aid Non –Motorized Transportation modes. (Figure 25)
- Pedestrian signals lack proper coordination and Countdown timers have not been provided to aid the pedestrians in crossing the intersection.

- Unruly behaviour by road users, especially Buses and IPT modes.

B) Countermeasures

- On the Northern Leg, a storage lane should be provided for the U-turn traffic.
- Shrubs blocking the line of sight of the cross traffic from the Northern leg should be removed.
- Bus stops with proper shelter should be provided on the far side on the Northern and eastern legs.
- On the major road, the Bus lane should be delineated.
- The signals need to be reworked due to lack of signal coordination, effect of upstream signals and the timers being improper.
- The left turn on the Northern leg should be protected.
- On the Northern leg, more time should be provided for the U-turn traffic.
- Adequate road signs to aid traffic should be provided.
- Longitudinal markings should be provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. should be provided to guide the flow of traffic.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators should be provided.
- Hazard markers must be provided near the canal on both Northern and Eastern approaches.
- Central rotary should be removed as it leads to queue spillback due to the vehicles standing near it violating the signal.
- Barricades placed on random locations on the road should be removed and the IPT modes should be discouraged from stopping at the intersection by means of proper enforcement.
- Sidewalks should be redesigned on the Southern and Eastern legs to improve their utility. And all sidewalks should be illuminated properly and connected to the intersection with the crosswalks. Proper Crossing facility should be provided on the Northern and Eastern legs.
- Road markings and signs should be provided to also aid Non –Motorized Transportation modes.
- Pedestrian signals should be recalibrated and Countdown timers should be provided to aid the pedestrians in crossing the intersection.

- Proper enforcement of Traffic rules is needed prevent unruly behaviour by road users, especially Buses and IPT modes.

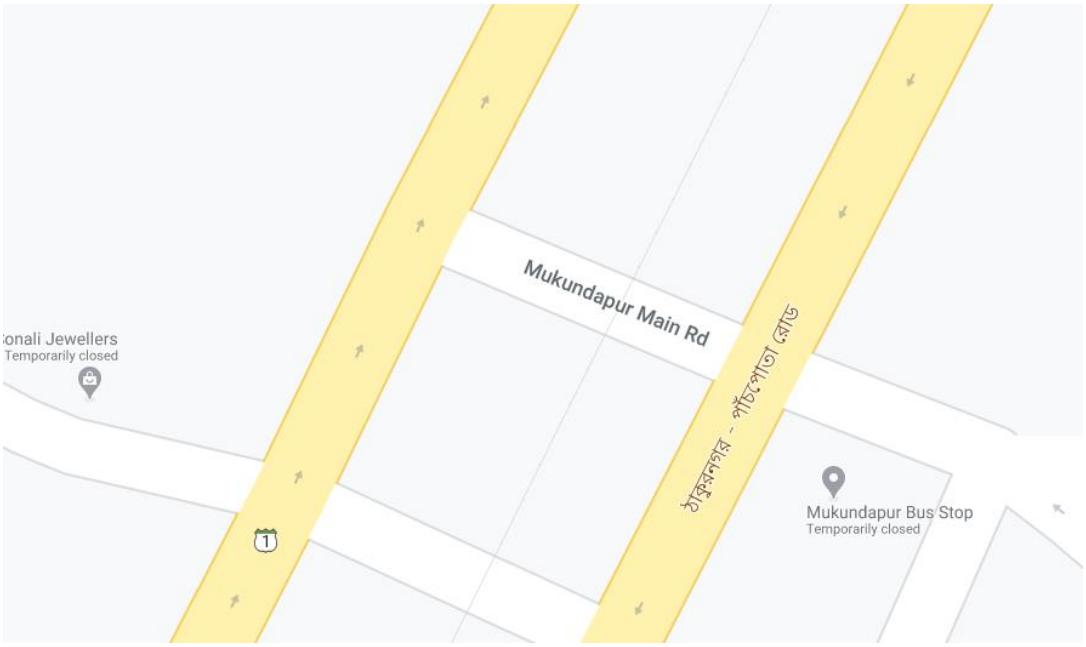

Figure 20 Junction layout of Mukundapur Intersection (Source: Google Maps)

Figure 21 Absence of Proper Bus stop and shelter

Figure 22 Proper Hazard markers and delineators needed

Figure 23 Improper barricade placement

Figure 24 Absence of Proper crossing facilities and road signs/markings for NMT users

Figure 25 Queue Spillback

5.1.4. Patuli Intersection

A) Safety Deficiencies

- Channelization for the left turn traffic absent on the Northern, Southern and Western legs.
- On the Eastern leg, many hand carts, NMT vehicles have been parked, encroaching the left turn storage lane. (Figure 28)
- The left turn storage lane on the southern leg is narrow and insufficient.
- The Median on the Southern Leg ends far before the intersection conflict area.
- Bus stop for the Western approach is located on the Northern approach, but Bus stops on nearside of the intersection. No Bus shelter has been provided on the Northern Leg.
- Amber time at the intersection is insufficient for NMT modes due to the up gradient.
- On the Southern leg, there is signal conflict with right turning traffic at North approach.
- Proper and adequate road signs to aid traffic have not been provided.
- Stop line on the southern and Eastern legs are too far from the intersection approach.
- Longitudinal markings have not been provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. are absent.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators have not been provided.
- Local encroachment by the vendors, Buses and Auto rickshaws.
- Sidewalks have not been designed to provide Barrier free access.
- The Green phase for the pedestrians is insufficient at the crossings on the Northern, Eastern and Southern Legs. The crossing movements of the pedestrians are also not protected from traffic.
- Road markings and signs have not been provided to aid Non –Motorized Transportation modes.
- Unruly behaviour by road users, especially by NMT, Buses and IPT modes. (Figure 29)

B) Countermeasures

- Proper channelization should be done for the left turn traffic on the Northern, Southern and Western legs.
- On the Eastern leg, all hand carts, NMT vehicles parked should be removed to free the left turn storage lane.
- The left turn storage lane on the southern leg needs to be widened.
- The Median on the Southern Leg should be extended towards the intersection.
- Shelters for the Bus stops should be provided on the Northern and Eastern approaches.
- Amber time at the should be increased.
- On the Southern leg, due to the signal conflict with right turning traffic at North approach, signals should be reworked.
- Adequate road signs to aid traffic should be provided.
- Stop line on the southern and Eastern legs should be brought closer to intersection approach.
- Longitudinal markings should be provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. should be provided to guide the flow of traffic.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators should be provided.
- Intersection should be cleared of the local encroachment by the vendors, Buses and Auto rickshaws.
- Sidewalks should be redesigned to provide Barrier free access.
- The Green phase for the pedestrians should be increased at the crossing on the Northern, Eastern and Southern Legs. The crossing movements of the pedestrians should be protected from the conflicting traffic.
- Road markings and signs should be provided to also aid Non –Motorized Transportation modes.
- Proper enforcement of Traffic rules is needed prevent unruly behaviour by road users, especially by NMT, Buses and IPT modes.

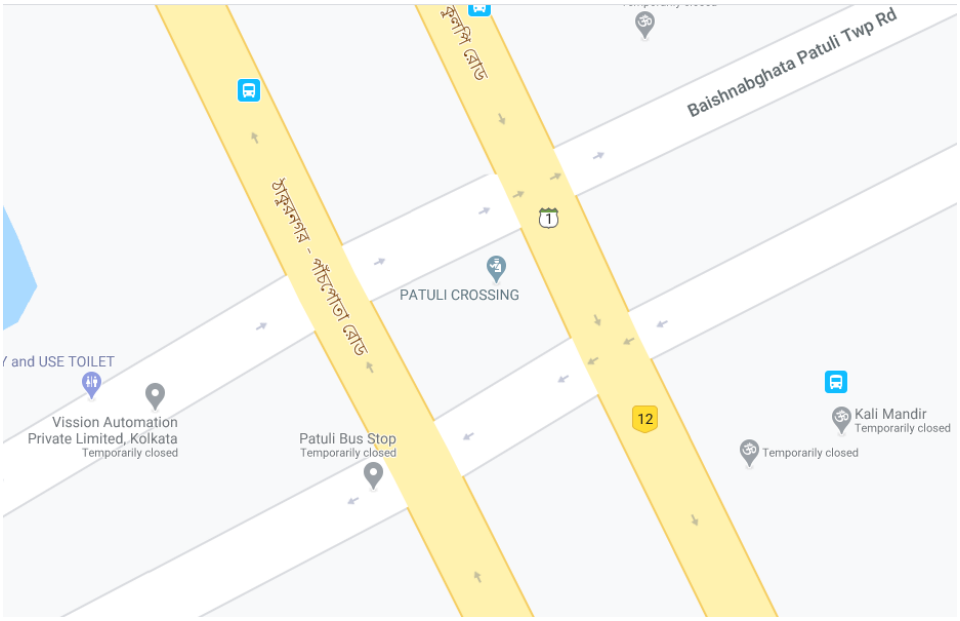

Figure 26 Junction Layout of Patuli crossing (Source: Google Maps)

Figure 27 Encroachment by Vendors

Figure 28 NMT users violating traffic rules

5.1.5. Ruby Intersection

A) Safety Deficiencies

- Channelizers for the left turning vehicles. Have not been provided on the Northern, Western and Southern legs.
- Right turn storage lanes on the Northern, Eastern and Western legs are narrow and insufficient.
- The median on the Eastern Leg is very short upstream.
- Pavement condition on the Northern, Southern and Eastern Legs need improvement. (Figure 31)
- No Bus shelter has been provided for the Bus stop at the Southern Leg.
- On the western leg, there is a lack of clarity about right turn due to Blinking Green. Secondary Signals on the Eastern Leg showing different phases from the primary signal. (Figure 32)
- Inter-Green Time provided is insufficient for such a large intersection.
- Inadequate signage to guide the road users through such a large and complex intersection.
- There are two stop lines on the Western leg. The stop line behind refuge island is correct. The stop line on the Eastern Leg is too far away from the intersection.
- Longitudinal markings have not provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. have not been provided.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators are absent.
- The intersection is encroached by Buses and IPT modes.
- Sidewalk on one side of the Eastern Leg is missing.
- Encroachment by parked vehicles on the Northern and Southern Legs.
- Sidewalks have not been designed to provide barrier free access.
- On the Western, Southern and Eastern Legs sometimes unauthorized stopping by buses seen near the intersection.
- Pedestrian signals on the Southern and Western legs are not working.
- Crossing movement on the Western leg conflicts with the permitted left turn traffic.
- Since the intersection is really large, frequent conflicts seen between pedestrian and vehicles.

- No Pedestrian countdown timers have been provided.
- No Road markings and signs have been provided to aid Non –Motorized Transportation modes.
- Unruly behaviour by road users, especially Buses and IPT modes.

B) Countermeasures

- Proper channelizers should be provided on the Northern, Western and Southern legs for the left turning vehicles.
- Right turn storage lanes on the Northern, Eastern and Western legs should be widened.
- The median on the Eastern Leg should be extended further upstream.
- Pavement condition on the Northern, Southern and Eastern Legs need improvement.
- Bus shelter should be provided for the Bus stop at the Southern Leg.
- On the western leg, there is a lack of clarity about right turn due to Blinking Green. Regular Green signal should be provided instead. Secondary Signals on the Eastern Leg showing different phases should be removed and only primary signals should be left.
- Inter-Green Time provided for all phases should be increased since the intersection is very large.
- Proper signage should be done at various places on the intersection.
- There are two stop lines on the Western leg. The stop line behind refuge island is correct and the other one should be erased. The stop line on the Eastern Leg should be moved closer to the intersection.
- Longitudinal markings should be provided on the eastern, southern and western legs.
- Continuity lines, directional lines, object markings etc. should be provided to guide the flow of traffic.
- Provisions to emphasize the delineation of merging and diverging areas like chevron signs and delineators should be provided.
- The intersection should be cleared of the local blockage by Buses and IPT modes.
- Sidewalk should be provided on one side of the Eastern Leg where it is missing.
- Encroachment by parked vehicles on the Northern and Southern Legs should be cleared.
- Sidewalks should be redesigned to provide barrier free access.
- Designated Bus stops with shelters should be provided at the Western, Eastern and Southern legs at the far side.

- Pedestrian signals on the Southern and Western legs should be repaired and recalibrated.
- Signal changes should be made to protect the pedestrians during the crossing movement on the Western leg with the permitted left turn traffic.
- Since the intersection is really large, foot overbridges or underpasses can be provided to assist pedestrian crossings and preventing conflicts.
- Pedestrian countdown timers should be provided at all legs of the intersection.
- Road markings and signs should be provided to also aid Non –Motorized Transportation modes.
- Proper enforcement of Traffic rules is needed prevent unruly behaviour by road users, especially Buses and IPT modes.

Figure 29 Junction Layout of Ruby Intersection (Source: Google Maps)

Figure 30 Poor Pavement condition

Figure 31 Right Turn signal on the Western Leg unclear

5.2. Signalized Intersections in Darmstadt, Germany

5.2.1. A1- Rheinstrasse/ Kavalleriesand

A) Safety Deficiencies

- No signage provided to denote No Entry for the left turn from the Western leg and through traffic movement from the Northern Leg.
- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- The crosswalk on the eastern Leg is in poor condition and no crossing facility provided on the Western leg.
- Separate cycle lanes have not been provided.
- Medians and Islands are not visible properly at night.

B) Countermeasures

- More signage is needed to denote No Entry for the left turn from the Western leg and through traffic movement from the Northern Leg.
- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- The crosswalk on the eastern Leg should be repainted and crossing facility should be provided on the Western leg.
- Separate cycle lanes can be provided on all legs, but not necessary.
- Reflectors or Markings can be provided on Medians and Island to improve night visibility.

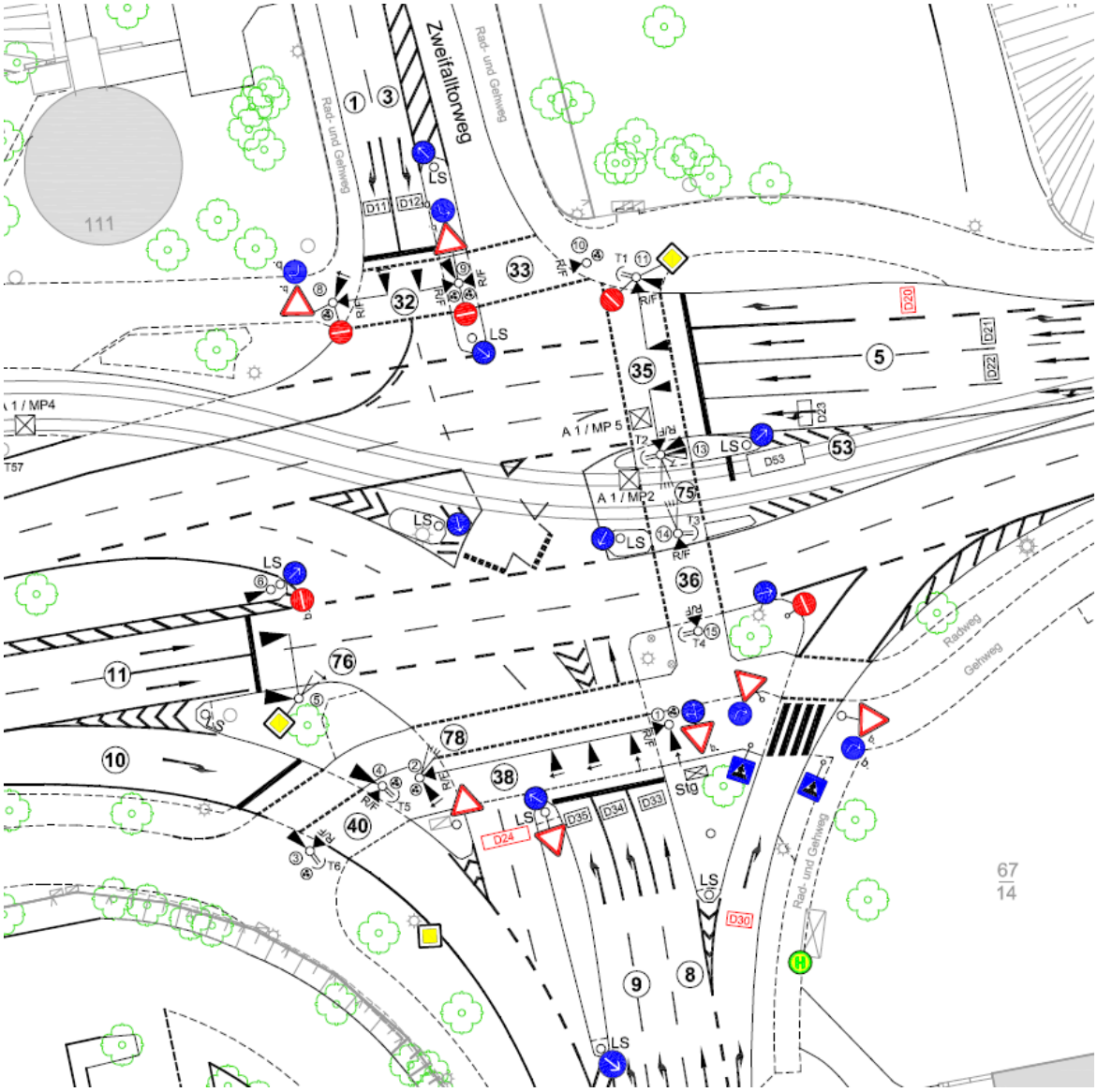

Figure 32 Junction layout of A1 intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.2. A2- Rheinstrasse/Berliner Alle

A) Safety Deficiencies

- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Inadequate signage provided on the Northern Leg to assist the drivers regarding the layout of the intersection and the priority rules.
- The Road Traffic Signal phases conflict with the trams sometimes.
- Medians and Islands are not visible properly at night.

B) Countermeasures

- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- More signage should be provided on the Northern Leg to assist the drivers regarding the layout of the intersection and the priority rules.
- There needs to be proper Co-ordination between the road signals and the tram signals.
- Reflectors or Markings can be provided on Medians and Island to improve night visibility.

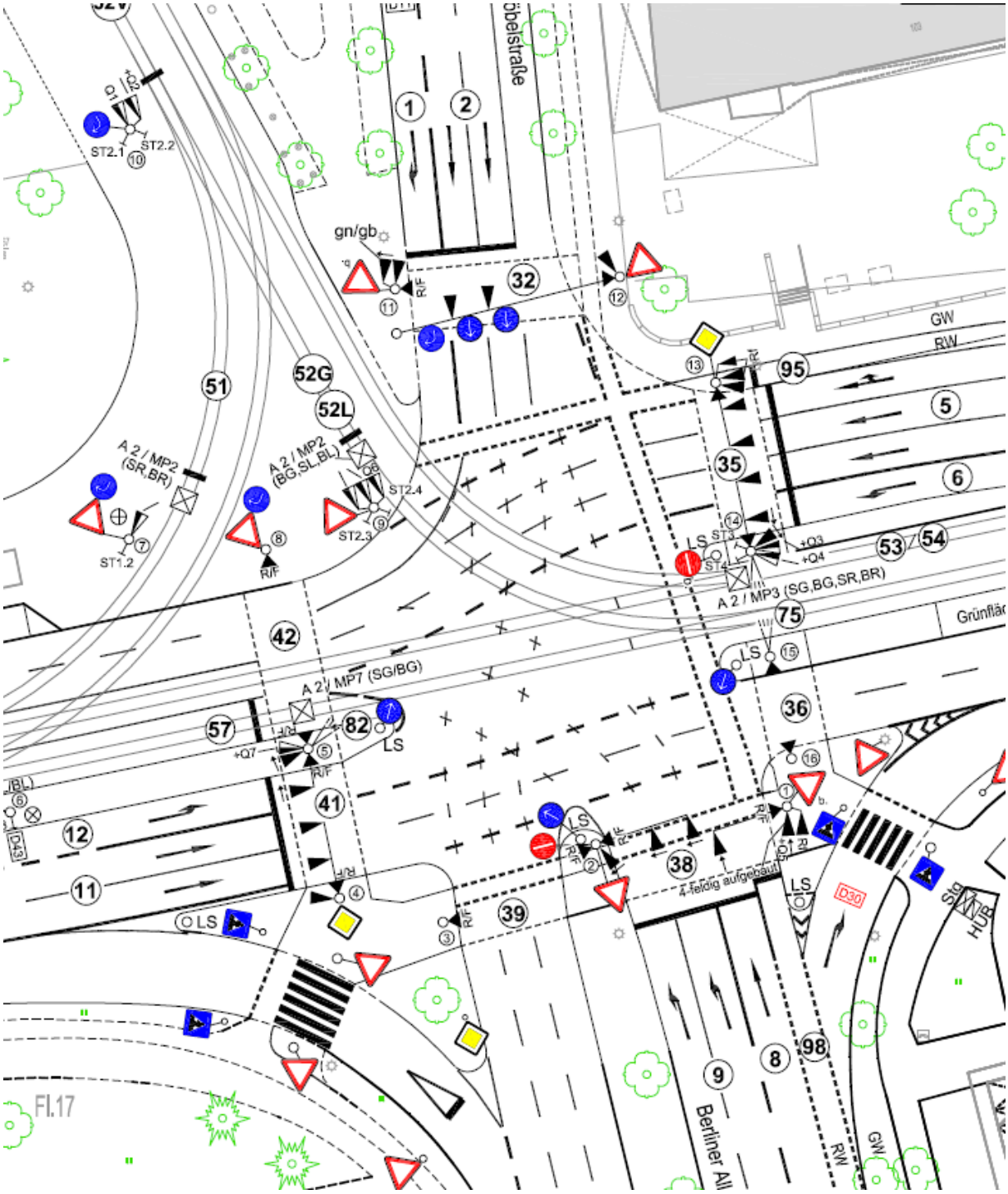

Figure 33 Junction layout of A2 Intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.3. A3- RheinStrasse/ HindenbergStrasse

A) Safety Deficiencies

- Left turn and Right turn phases on the Northern and Southern Legs are permitted along with the through phase.
- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Medians and Islands have poor night visibility.
- Road signs are not visible at night.

B) Countermeasures

- Left turn and Right turn phases on the Northern and Southern Legs should be segregated from the through phase and protected.
- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- Reflectors or Markings can be provided on Medians and Island to improve night visibility.
- Road signs should be illuminated properly at night.

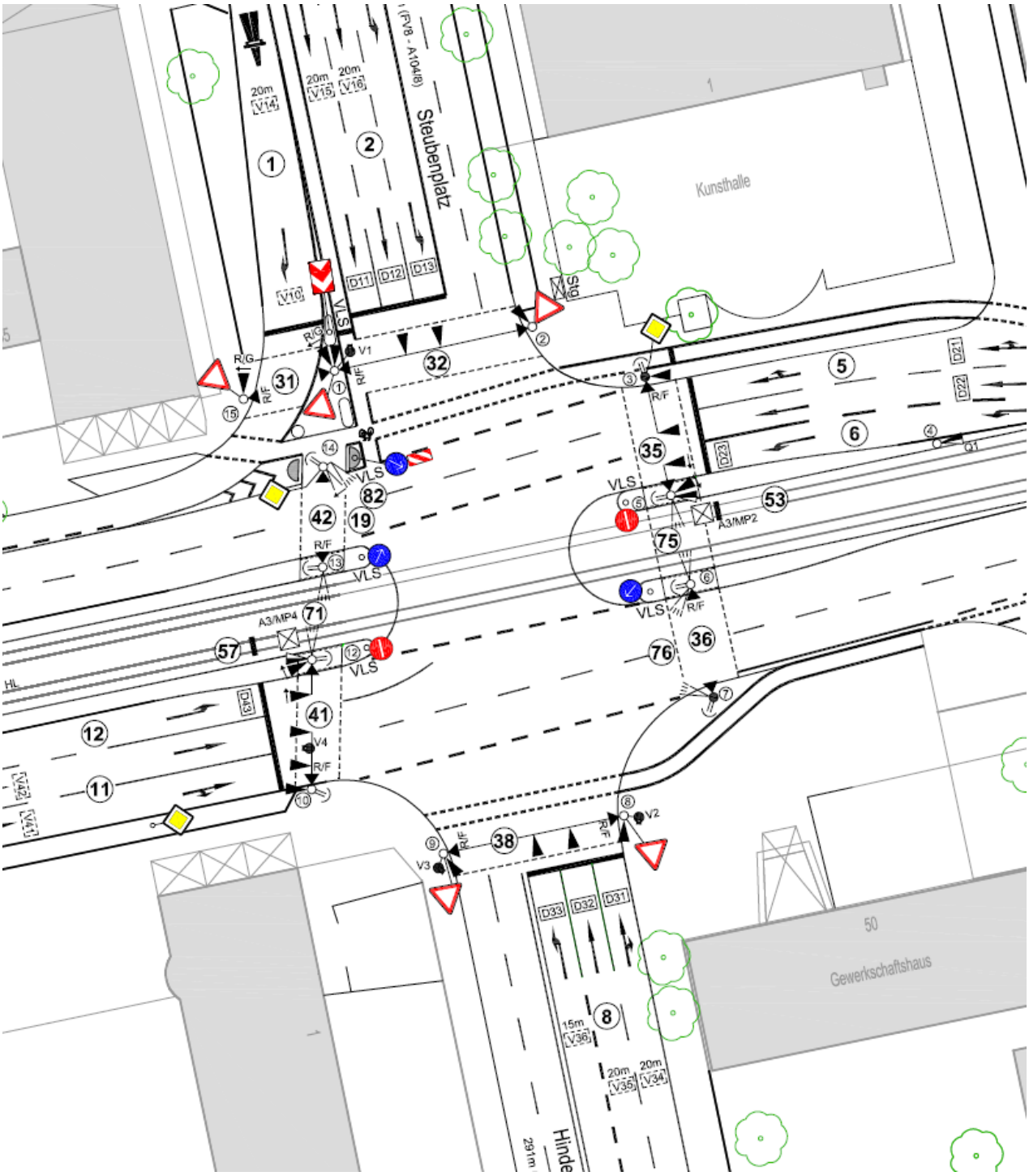

Figure 34 Junction layout of A3 Intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.4. A4- Rheinstrasse/Neckarstrasse/Kasinostrasse

A) Safety Deficiencies

- Inadequate signage provided on the Western Leg to assist the drivers regarding the layout of the intersection and the priority rules.
- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Sign boards should be illuminated properly to improve visibility at night.

B) Countermeasures

- More Signage needed on the Western leg to assist the needs of unfamiliar drivers so that the junction layout and priority rules can be recognized by the drivers well in advance.
- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- Sign boards should be illuminated properly to improve visibility at night.

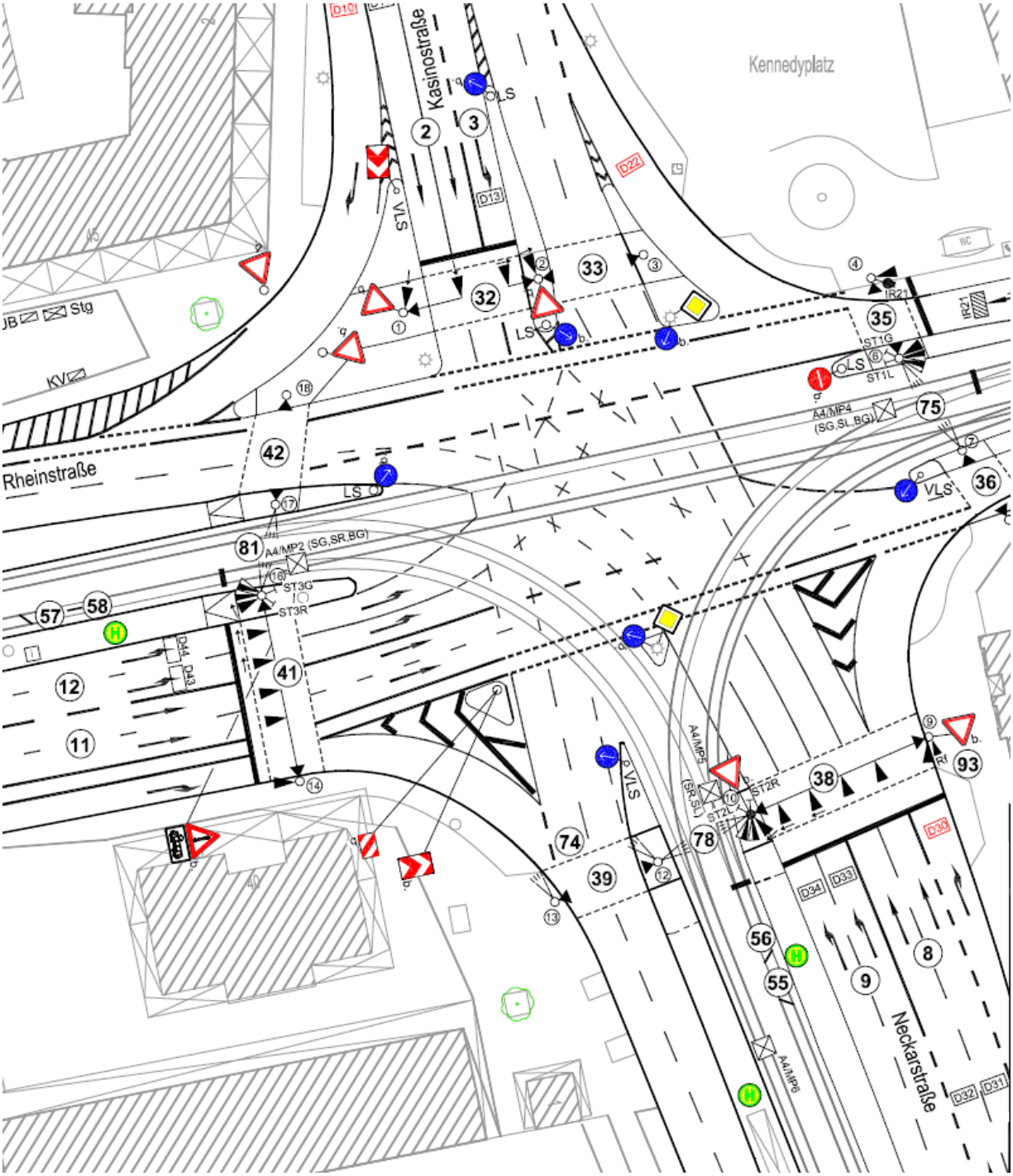

Figure 35 Junction layout of A4 intersection, Dramstadt (Source: Darmstadt Town hall)

5.2.5. A12- Kasinostrasse/Bismarckstrasse:

A) Safety Deficiencies

- Left turn phases on the Northern and Southern legs are permitted which leads to conflicts with the through traffic.
- Inadequate Signage on the Northern and Southern legs to assist the needs of unfamiliar drivers so that the junction layout and priority rules can be recognized by the drivers well in advance.
- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Pavement condition on the Eastern leg relatively poor.
- Visibility at the Eastern leg is poor at night.

B) Countermeasures

- Left turn phases on the Northern and Southern legs should be protected to prevent conflicts with through traffic.
- More Signage needed on the Northern and Southern legs to assist the needs of unfamiliar drivers so that the junction layout and priority rules can be recognized by the drivers well in advance.
- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- Pavement condition on the Eastern leg should be improved.
- Illumination at the Eastern leg needs improvement to increase visibility at night.

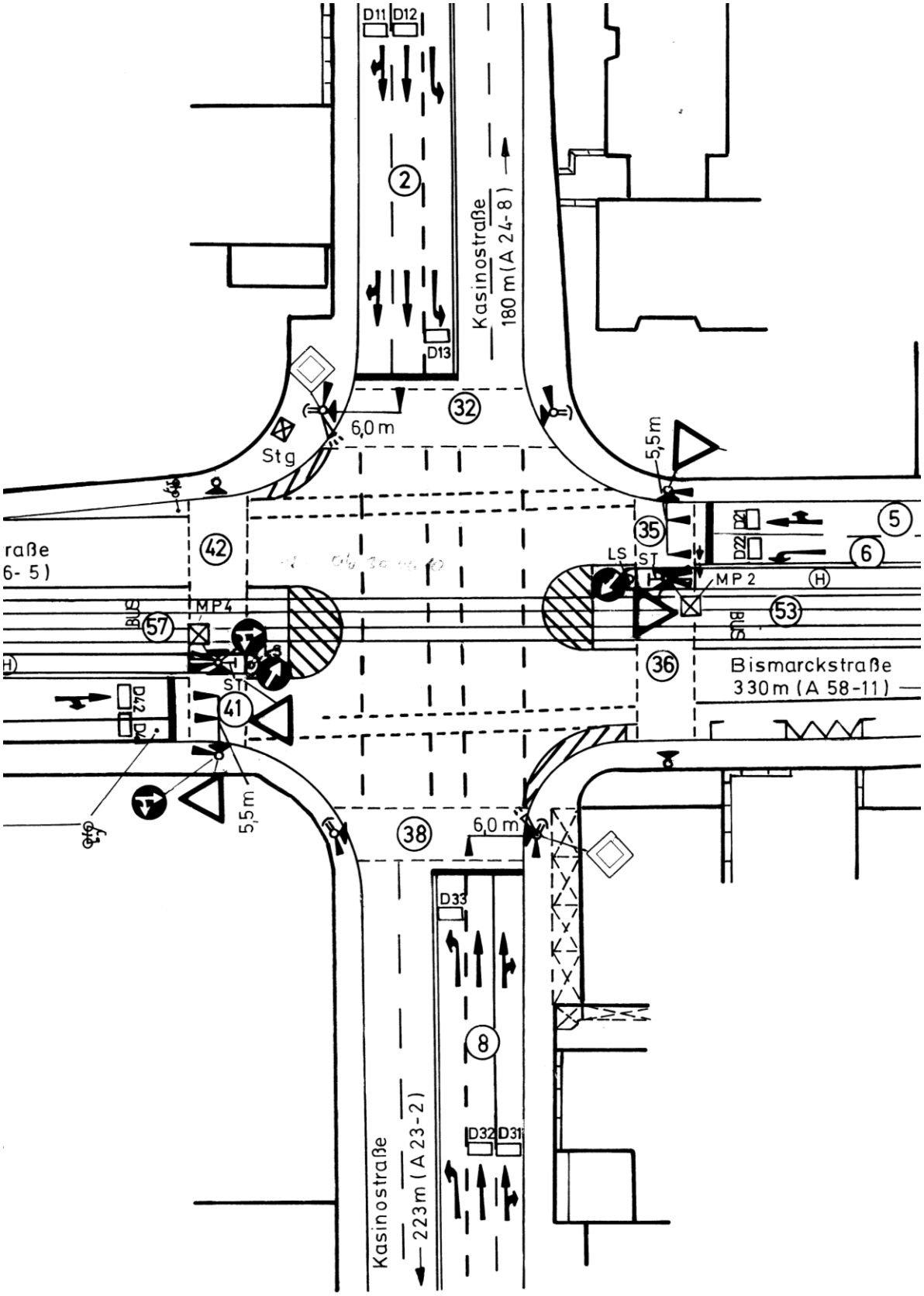

Figure 36 Junction layout of A12 intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.6. A13- Heidelbergerstrasse/ Heinrichstrasse

A) Safety Deficiencies

- Left turning vehicles on the Eastern Leg are permitted which leads to conflict with the through traffic.
- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Sign boards have poor visibility at night.

B) Countermeasures

- Left turning vehicles on the Eastern Leg should be protected to prevent conflict with the through traffic.
- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- Sign boards should be provided with better illumination for night visibility.

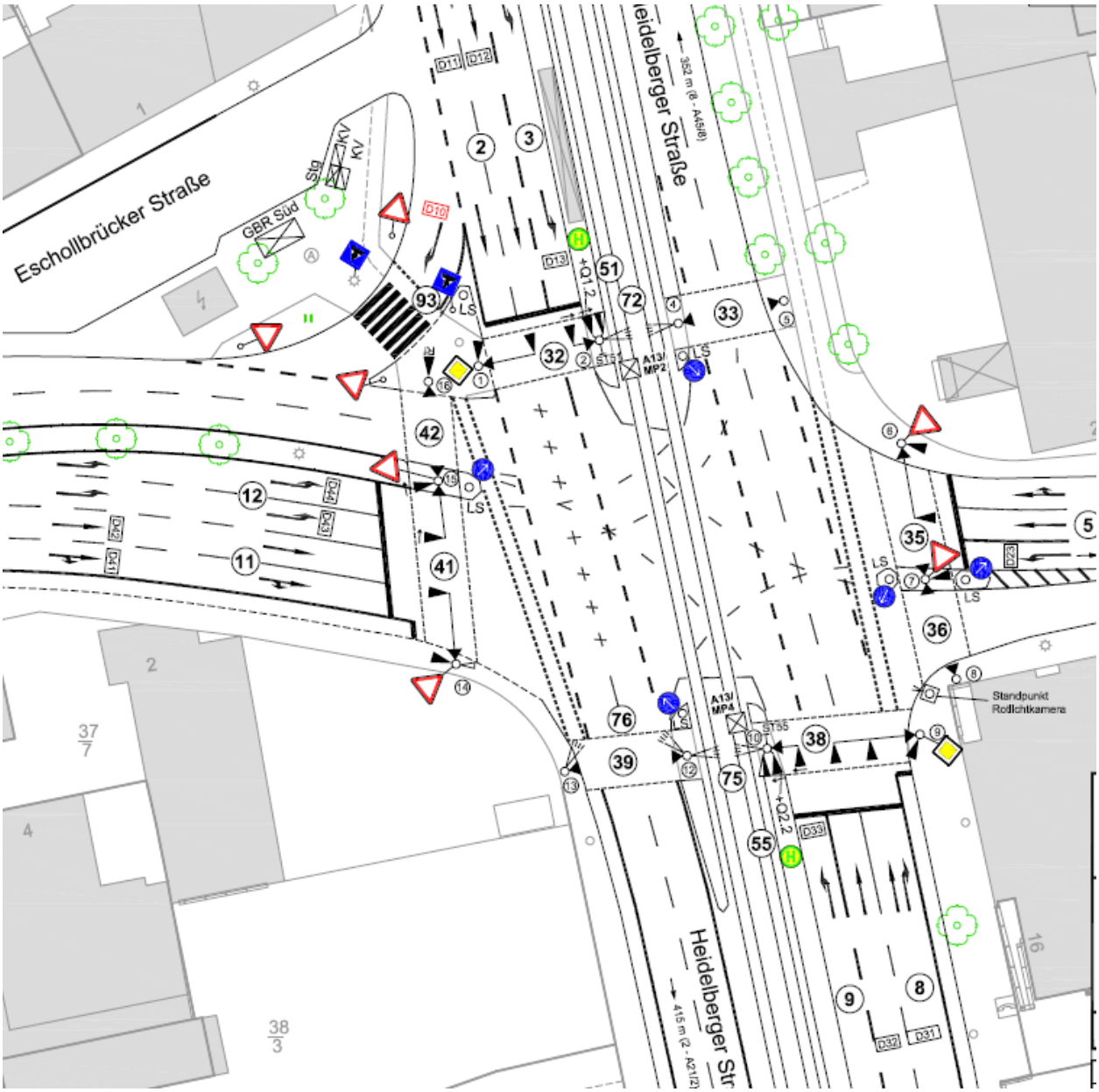

Figure 37 Junction Layout of A13 Intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.7. A22- Neckarstrasse/Elizabethenstrasse

A) Safety Deficiencies

- Left turn phases and right turn phases on the Northern and Southern legs are permitted which leads to conflicts with the through traffic.
- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Inadequate Signage provided on the Northern, Eastern and Southern legs to assist the needs of unfamiliar drivers.
- Road markings have poor visibility at night.
- Road Signs are not visible properly at night.

B) Countermeasures

- Left turn phases and right turn phases on the Northern and Southern legs should be protected to prevent conflicts with through traffic.
- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- More Signage needed on the Northern, Eastern and Southern legs to assist the needs of unfamiliar drivers so that the junction layout and priority rules can be recognized by the drivers well in advance.
- The condition of road markings should be improved and illumination of the approaches should be increased to increase visibility at night.
- To improve the visibility of the sign boards at night, proper illumination must be done.

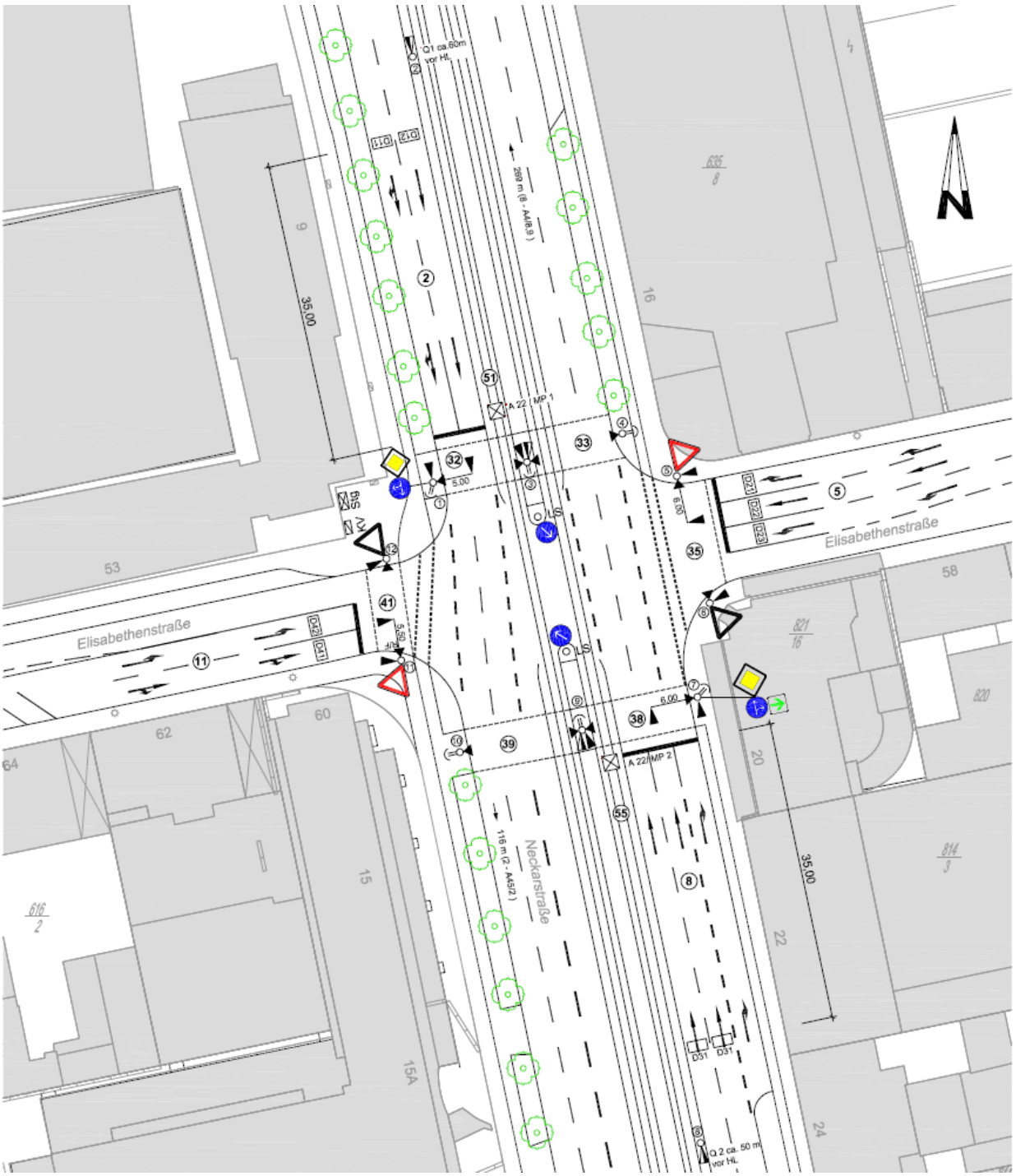

Figure 38 Junction Layout of A13 intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.8. A23- Kasinostrasse/ Bleichstrasse

A) Safety Deficiencies

- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Sign boards have poor visibility at night.
- Motorists were seen to be frequently speeding up to clear the intersection during the green phase, especially at night.

B) Countermeasures

- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- Sign boards should be illuminated properly for better visibility at night.
- Proper enforcement of Traffic rules is needed to discourage the habit of speeding up to clear the intersection during the green phase, especially at night.

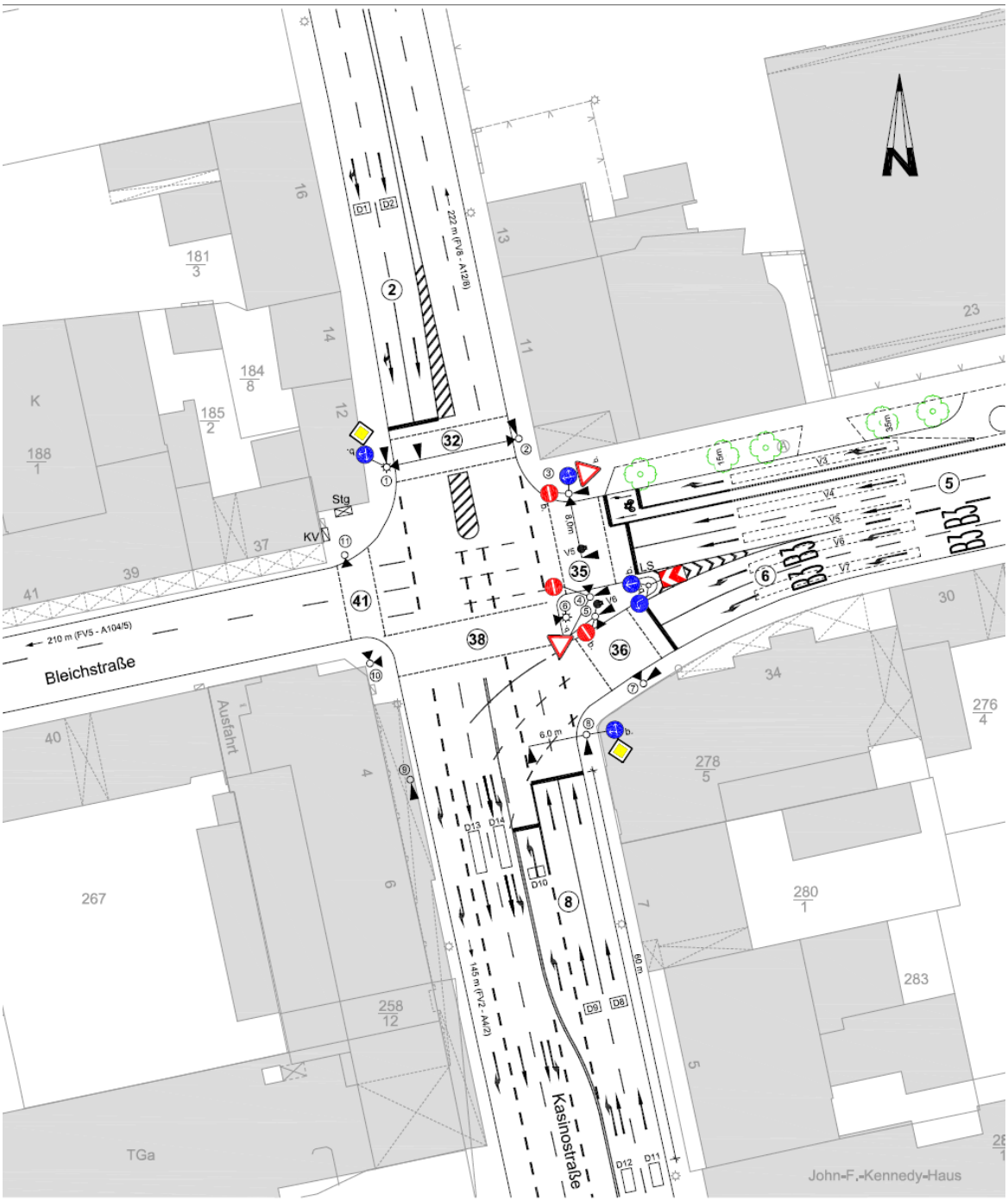

Figure 39 Junction layout of A23 Intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.9. A24- Kasinostrasse/ Julius-Reiber-Strasse

A) Safety Deficiencies

- Inadequate Signage provided to assist the needs of unfamiliar drivers so that the junction layout and priority rules can be recognized by the drivers well in advance.
- Subway crossing facilities on the Northern and Southern legs do not have barrier free access.
- Poor visibility of the intersection and sign boards at night.
- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.

B) Countermeasures

- More Signage needed on all legs to assist the needs of unfamiliar drivers so that the junction layout and priority rules can be recognized by the drivers well in advance.
- Ramps/lifts should be provided at the subway crossing facility on the Northern and Southern legs to ensure barrier free access.
- Better illumination needed at night to improve visibility of the intersection and sign boards.
- Green phase for pedestrians on the exit lanes of all legs, should be protected.

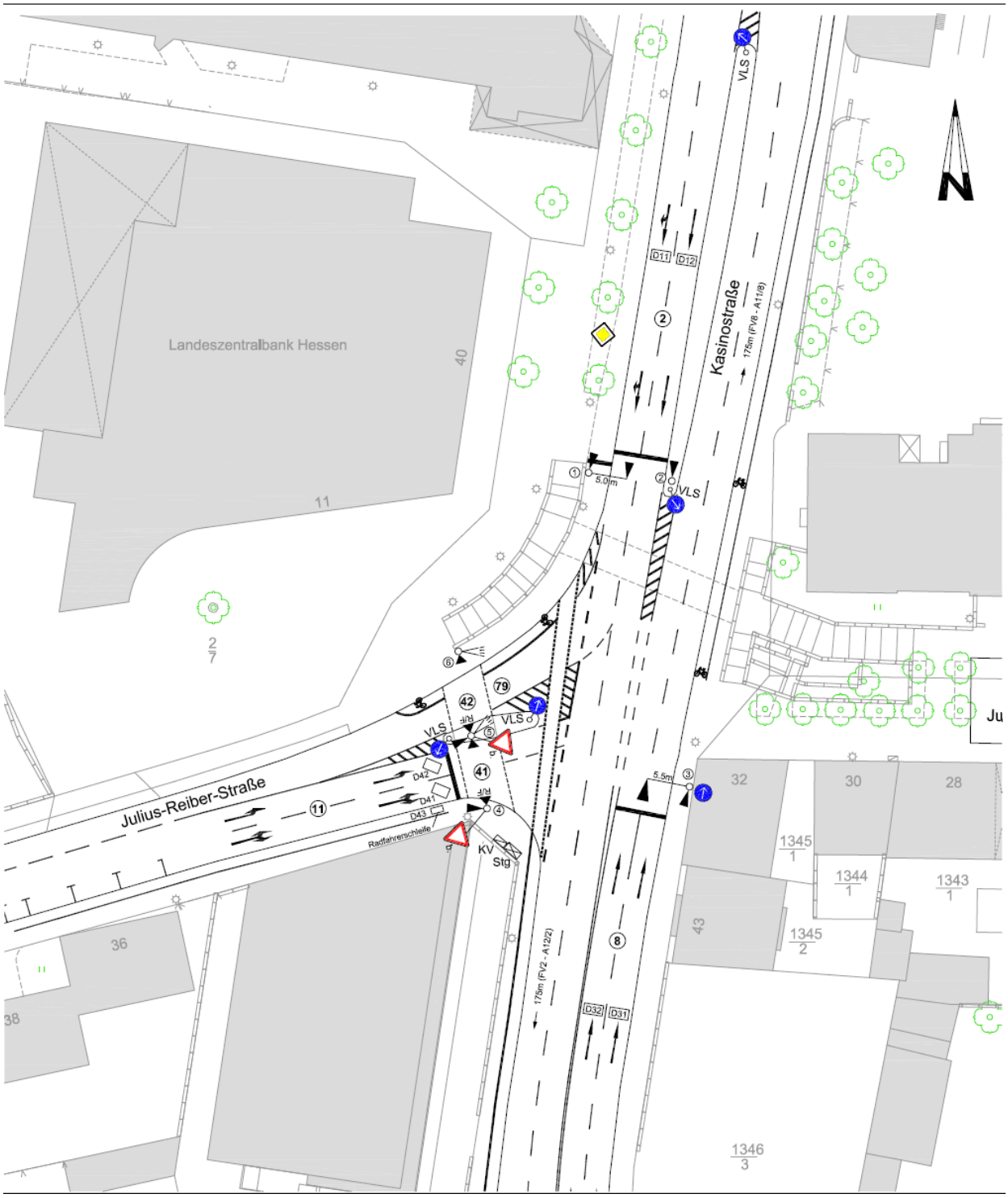

Figure 40 Junction Layout of A24 intersection, Darmstadt (Source: Darmstadt Town hall)

5.2.10. A45- Neckarstrasse/Hugelstrasse

A) Safety Deficiencies

- Green phase for pedestrians on the exit lanes of all legs, conflicting with right turning cross traffic during the Green phase.
- Sign boards have poor visibility at night.

B) Countermeasures

- Green phase for pedestrians on the exit lanes of all legs, should be protected.
- Illumination needs improvement for better visibility of sign boards at night.

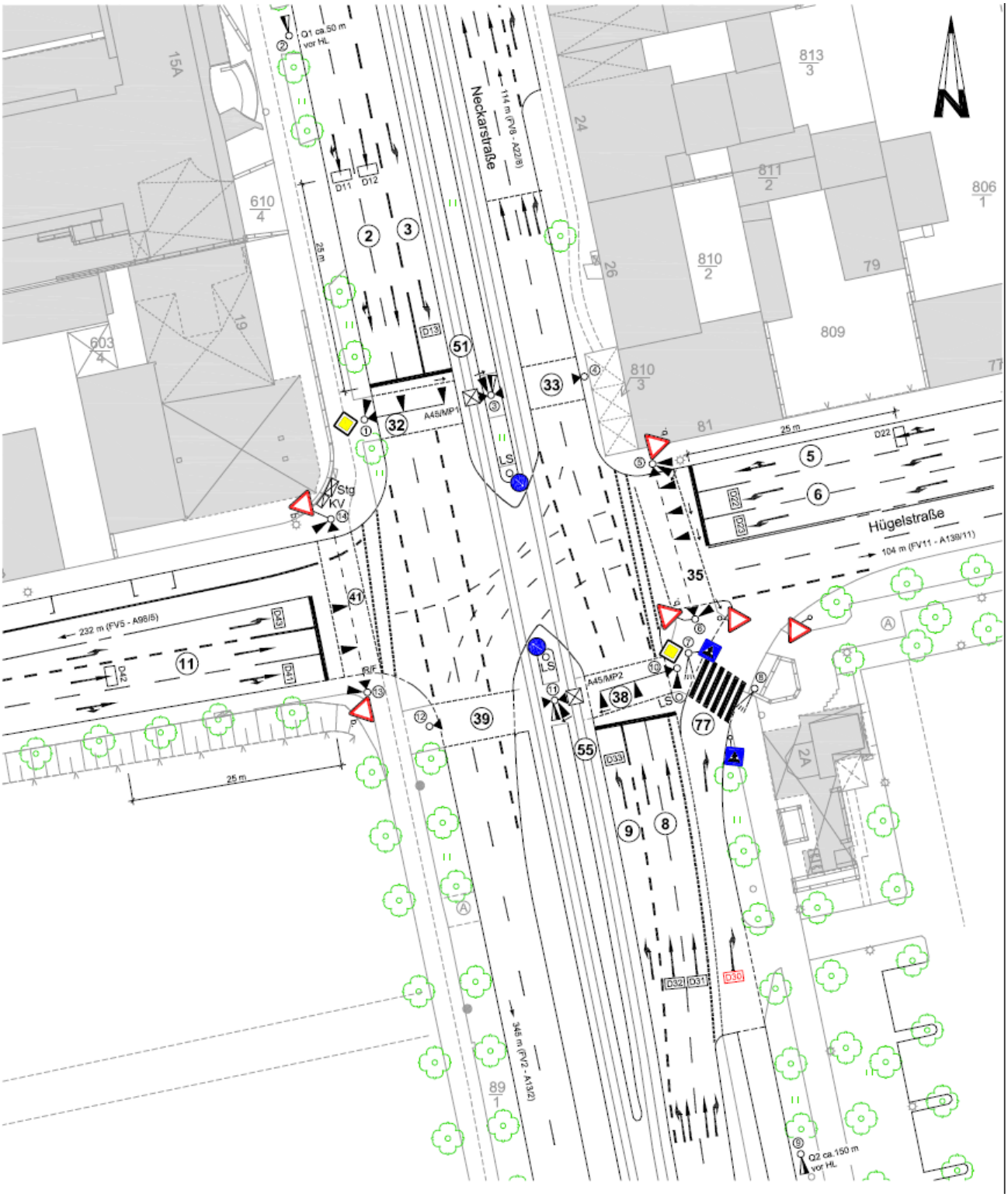

Figure 41 junction Layout of A45 Intersection, Darmstadt (Source: Darmstadt Town hall)

5.3. Differences between Indian and German Intersections

Some differences observed between the signalized intersections in the two countries are as follows:

1. Higher priority is given to pedestrians and Non-Motorized Vehicles in Germany compared to India.
2. Conditions of the road infrastructure and road side furniture are far better in Germany than in India. (Figure 43)
3. The compliance of various road users to the traffic rules and regulations in Germany is drastically better than in India.
4. The management related issues like encroachment and traffic violations are dealt in a better way in Germany than India.
5. The overall safety levels of signalized intersections in Germany are far higher than in India.

Figure 42 Well Designed Intersections in Germany

6 Conclusion

6.1. Summary

With the increasing number of vehicles on the roads, the number of accidents is also on the rise. Urban Intersections, in particular, are very prone to such accidents, since that is where the likelihood of conflicts between various Road users is the highest. Most of these Urban intersections have been converted into signalized intersections with time, leading to an increase in their safety. But even after such improvement, they are still quite prone to accidents, either due to safety deficiencies in them or due to unruly behaviour by the road users. As such, an attempt has been made in this study to help identify the safety deficiencies at Signalized Urban intersections. Some Literature has been established to identify the accident causal factors at Urban intersections as already discussed in this study, but there was a need to prepare a comprehensive framework with the help of which all the safety deficiencies, taking all the safety aspects under account, could be identified. Road safety manuals and audit guidelines have been developed by various agencies across the globe, but even they have been found to be lacking in certain aspects of Road safety. So, an intense literature review was conducted to identify all the accident causing factors and the related safety elements, in order to prepare a comprehensive framework with the help of which all the Safety deficiencies at signalized intersections could be identified. The safety elements identified through Literature Review were then categorized under eight Safety aspects i.e. Geometric Design characteristics, Traffic signal elements, Road sign elements, Road Marking elements, Management Issues, Pedestrian Safety Elements, Non-Motorized Transportation Safety Elements and Road User Behaviour at the intersection. This was followed by the development of a questionnaire with the help of which intersections could be assessed by the auditors. In the questionnaire, the auditor would rate all the individual safety elements at all legs of the intersection, followed by the overall safety aspect of these legs. This information would then be used by the auditor to rate the overall safety aspect of the intersection and finally the overall safety of the intersection. All these ratings are merely qualitative in nature and do not accurately reflect the safety of intersections. Further work is needed to rate the intersections and quantify their safety level as discussed in section 6.3. In this study one corridor in Kolkata, India and two corridors in Darmstadt, Germany were selected on account of the high traffic volume and crash rates there, for the application of this framework. In total, five intersections in Kolkata and ten intersections in Darmstadt were studied. The safety deficiencies at these intersections were identified by the experts, and several countermeasures were proposed as highlighted in section 5, in order to improve the safety level of these intersections. It was found that there are many design deficiencies; absence of proper infrastructure to control traffic like road markings and road signs; absence of proper sidewalks, crossing facilities, pedestrian signals and pedestrian countdown timers; poor enforcement of the traffic rules and unruly Road user behaviour at the intersections in Kolkata, leading to conflicts and unsafe road conditions. On the contrary, in Darmstadt, the major issues are lack of proper illumination at night in many intersections and permitted left/ right turning phases at some intersections. Overall, it was found that the German intersections are safer than their Indian counterparts, owing to better Design, Infrastructure, Management and Road user behaviour in Germany.

6.2. Major Contributions

The major contributions by the author in this study have been highlighted below:

- Intensive Literature review to identify the accident causal factors at signalized intersections.
- Development of a comprehensive framework with the help of which the safety deficiencies of signalized urban intersections can be recognized.
- Application of the framework to five intersections in the Kolkata metro city, India with the help of other experts and ten intersections in Darmstadt, Germany.
- Identification of major safety deficiencies for these intersections in Kolkata and Darmstadt.
- Proposal of several countermeasures to fill these safety deficiencies and improve the safety level of the intersections.
- Comparison of the safety level of the signalized intersections in India and Germany.

6.3. Future Research Scope

This framework has been developed exclusively to identify the safety deficiencies at at-grade signalized urban intersections. In the future, further research can be carried out to improve on this work as highlighted below:

- It needs to be modified to assess non-signalized intersections in urban and rural areas.
- It also needs further improvement for application at complex grade-separated intersections in urban Metropolitan areas.

A mathematical model can be developed to assign weights to various safety aspects and their corresponding safety elements discussed earlier. Once, the weights of these factors are determined, the study can be applied to quantify the safety level of urban signalized intersections. This can come handy in situations where accident data is not available to judge the safety level of intersections through crash data analysis, which is often the case in developing countries like India.

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8 Annexure

Appendix I Questionnaire

Date: Time:

Audit questionnaire for the evaluation of safety at Signalized Urban Intersection

Intersection name: **Type of survey:** Peak day/Peak Evening/Off-peak Night

Name of Auditor: **Number of Approaches in the Intersection:**

Please answer the following questions for the intersection safety based on a scale of 1 to 5, based on the survey:

1	2	3	4	5
Very Poor	Poor	Average	Good	Excellent

S.no.	Questions:	N	E	S	W	Remarks
A) Geometric Design Characteristics:						
1	Rate the adequacy of the junction for all allowable vehicular movements and for all types of vehicles.					
2	Rate how clear is the route through the intersection to the approaching motorist, so that the junction type, layout and the priority rules can be recognized by approaching motorists well in advance.					
3	Rate how adequate is the provision and alignment of channelisers and traffic islands at appropriate locations to improve junction conspicuity and ensure orderly flow of traffic.					
4	Rate the presence and sufficiency of the storage area of left turning lane at the intersection.					
5	Rate the presence and sufficiency of the storage area of right turning lane at the intersection.					
6	Rate the sufficiency of the roadway width and capacity at the exit to ensure smooth movement of the entering vehicles.					

S.no.	Questions:	N	E	S	W	Remarks
7	Rate how appropriate is the provision and alignment of the median divider for two-way traffic at the intersection.					
8	Rate how adequate is the intersection sight distance and line of sight to the conflicting traffic, pedestrians and traffic control elements from the stop line.					
9	Rate how adequate and appropriate is the turning radius for right turning vehicles at the intersection approach under consideration.					
10	Rate how adequate and appropriate is the turning radius for left turning vehicles at the intersection approach under consideration.					
11	Rate the presence and location of bus stop at the intersection in terms of safety and efficiency.					
12	Rate how well the bus stop is segregated from the traffic lanes.					
13	Rate how adequate is the Bus stop design in terms of capacity and frequency of bus arrival/departure.					
14	Rate the adequacy of speed management provisions					
15	Rate the overall geometric design of each approach					
16	Rate the overall geometric design of the intersection					
B) Traffic Signal elements:						
1	Rate the visibility of the Traffic signal up to a distance of 50 metres from the stop line.					
2	Rate how clearly do the signals indicate which movements are allowed at one time.					
3	Rate how appropriate is the location of the signals for competing phases so that they are only visible to traffic for which they are intended.					
4	Rate how sufficient is the green					

S.no.	Questions:	N	E	S	W	Remarks
	time provided for the through traffic stream emerging from the intersection leg under consideration.					
5	Rate how efficiently is the green time utilized at the leg of the intersection under consideration.					
6	Rate how adequate is the amber time in the signal cycle.					
7	Rate how sufficient is the inter-green time provided.					
8	Rate how protected is the left turn traffic to prevent sideswipe with cross traffic.					
9	Rate how adequate is the timing of the left turn phase.					
10	Rate how protected is the right turn traffic to prevent sideswipe with cross traffic.					
11	Rate the adequacy of the timing of right turn phase for the approach under consideration.					
12	Rate the overall performance of traffic signal elements of each approach					
13	Rate the overall performance of traffic signal elements of the intersection					
C) Road Signs:						
1	Rate how proper and adequate are the road signs (regulatory, warning and informational signs) in accordance with the standards.					
2	Rate how appropriate is the spacing and placement of the road signs (too many signs should not be placed close to each other; should not affect the line of sight for drivers and pedestrians).					
3	Rate the visibility of road signs for the intended road users.					
4	Rate how appropriately the signage is done at locations along the junction layout to assist drivers and satisfy the needs of the unfamiliar driver.					
5	Rate the provision, visibility and					

S.no.	Questions:	N	E	S	W	Remarks
	adequacy of the intersection sign on the approach for the road users.					
6	Rate the provision, visibility and adequacy of the advance direction sign.					
7	Rate the provision, visibility and adequacy of the distance information sign.					
8	Rate the overall performance of road signs of each approach					
9	Rate the overall performance of road signs of the intersection					
D) Road Markings:						
1	Rate the visibility of the stop line for the approaching motorist.					
2	Rate how appropriate is the location of the stop line from the intersection.					
3	Rate the adequacy and visibility of longitudinal markings (like lane markings, median markings, edge lines, bus lane markings, centre line markings etc.) at the intersection approaches.					
4	Rate how adequate and visible are the intersection markings other than crossings and stop lines (like continuity lines, directional arrows, give way, box markings etc.) marked on the pavement to guide the driver.					
5	Rate how adequate and visible are the object markings (like kerb markings, island markings etc.) at the intersection and its approaches to warn the driver.					
7	Rate how adequate are the provisions to emphasize the delineation of merging and diverging areas with the help of delineators and chevron signs.					
8	Rate how adequate is provision and visibility of 'Hazard markers' at approach end of island, medians, other obstructions and upon lane/median transition.					

S.no.	Questions:	N	E	S	W	Remarks
9	Rate the overall performance of road markings of each approach					
10	Rate the overall performance of road markings of the intersection					
E) Management Issues:						
1	Rate the condition of queue spillback from the downstream intersection preventing the entering vehicles from clearing the intersection.					
2	Rate the pavement surface grip of the approach so that the skidding of vehicles while stopping is avoided.					
3	Rate how free is the intersection functional/conflict area from local blockage (Bus stop, Bus not stopping at the designated lane, parking, encroachment).					
4	Rate how clear of unwarranted stationary obstacles (like large potholes, open manholes etc.) is the intersection for the traffic stream emerging from the direction under consideration.					
5	Rate how clear is the intersection of unwarranted movable obstacles like handcarts, animals etc..					
6	Rate how well regulated is the movement of NMT vehicles on the leg of the intersection under consideration.					
7	Rate how is the overall illumination condition at the intersection so that all road users are visible to each other.					
8	Rate the overall management of each approach					
9	Rate the overall management of the intersection					
F) Pedestrian Safety:						
1	Rate how adequate is the sidewalk facility in terms of width/capacity.					
2	Rate how much is the footpath free of encroachment to the pedestrians.					

S.no.	Questions:	N	E	S	W	Remarks
3	Rate the condition of the footpath (in terms of pavement condition and clear of trash, debris, snow etc.) for pedestrian use.					
4	Rate the appropriateness of the pedestrian facilities in providing barrier free access.					
5	Rate how adequate is the capacity of waiting area for the designated bus stop/taxi stop etc., if the designated stop is present at/near the intersection block.					
6	Rate how sufficient is the illumination at the sidewalk/ designated bus/taxi stop waiting area.					
7	Rate how well connected are the sidewalks with the crossing facility.					
8	Rate how accessible is the crossing facility from both ends.					
9	Rate how free is the crossing facility from encroachment and available to the pedestrians for easy use.					
10	Rate how good and well maintained is the crossing facility.					
11	Rate how adequate is the width/capacity of the crossing facility to ensure adequate opportunity for crossing.					
12	Rate how adequate is the illumination at the crossing facility so that it is visible to pedestrian and motorists.					
13	Rate position and visibility of the pedestrian signals.					
14	Rate how protected are the crossing movements from conflicting through traffic movements.					
15	Rate how protected are the crossing movements from conflicting right turn traffic movements.					
16	Rate how protected are the crossing movements from					

S.no.	Questions:	N	E	S	W	Remarks
	conflicting left turn traffic movements.					
17	Rate the provision, visibility and adequacy of the pedestrian countdown timer.					
18	Rate how appropriate and bearable is the waiting time for the pedestrians at the crossing.					
19	Rate how adequate is the Clearing time for the pedestrians.					
20	Rate the overall pedestrian safety performance of each approach					
21	Rate the overall pedestrian safety performance of the intersection.					
G)	**NMT (excluding pedestrians) Safety:**					
1	Rate how protected are the crossing movements from conflicting traffic movements.					
2	Rate how proper, adequate and visible are the road markings/signs provided for NMT users to make proper manoeuvres on the intersection.					
3	Rate the adequacy of the green time for the NMT users.					
4	Rate how adequate is the clearance time for NMT users.					
5	Rate how safe and adequate are the crossing facilities for NMT users.					
6	Rate the overall NMT safety performance of each approach					
7	Rate the overall NMT safety performance of the intersection					
H)	**Road User Behaviour:**					
1	Rate how compliant is the behaviour of the drivers in terms of not crossing the stop line during red signal.					
2	Rate how compliant is the driver behaviour against stopping during green time (excluding PT/IPT modes).					
3	Rate how compliant is the behaviour of the drivers in terms of not making dangerous manoeuvres (other than stopping during green time).					

S.no.	Questions:	N	E	S	W	Remarks
4	Rate how compliant is the behaviour of IPT/PT drivers in terms of not making unauthorised stops at the intersection.					
5	Rate how compliant is the behaviour of the drivers in terms of not speeding up to clear the intersection during green time.					
6	Rate how compliant is the behaviour of the drivers in terms of not stopping suddenly when the signal turns to red again.					
7	Rate how compliant is behaviour of the pedestrians in terms of using the designated crossing facilities.					
8	Rate how compliant is the pedestrian behaviour in terms of using the sidewalk/designated PT/IPT stopping facility.					
9	Rate how compliant is the behaviour of NMT users (other than pedestrians) in terms of following the traffic rules at the intersection.					
10	Rate the overall road user behaviour of each approach.					
11	Rate the overall road user behaviour of the intersection.					

Rate the overall safety performance of the intersection	1	2	3	4	5

Recommendations:

Based on answers you might have given to the questions above, please answer the following questions to classify the five Satisfaction Levels you would have used in answering the survey using a scale from 0% to 100%.

Example:

"I will answer in 'Very poor' when Satisfaction level ranges from 0% to 10%."

I will answer in 'Very Poor' when Satisfaction level ranges from

_____% to _____%.

I will answer in 'Poor' when Satisfaction level ranges from

_____% to ____%.

I will answer in 'Average' when Satisfaction level ranges from

_____% to _____%.

I will answer in 'Good' when Satisfaction level ranges from

_____% to _____%.

I will answer in 'Excellent' when Satisfaction level ranges from

_____% to _____%.

****