How do Road Users Negotiate Signalised Intersections at Right turns? An Analysis using Social Networks

A thesis submitted in the partial fulfilment of the requirement for the degree of

MASTER OF ARTS IN PSYCHOLOGY

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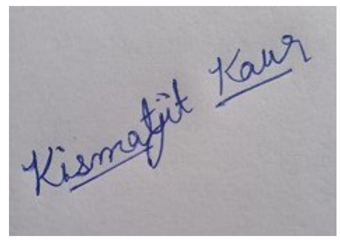
CERTIFICATE

This is to certify that the thesis entitled, ‘How do Road Users Negotiate Signalised Intersections at Right turns? An Analysis using Social Networks’ is being submitted in partial fulfilment of requirements for the award the of the degree of Master of Arts in Psychology, presented in the Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala is a Bonafede work carried out under the supervision of Dr.Ipshita Chowdhury, Assistant Professor , Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala and that no part of this project has been submitted for the award of any other degree.



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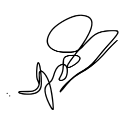

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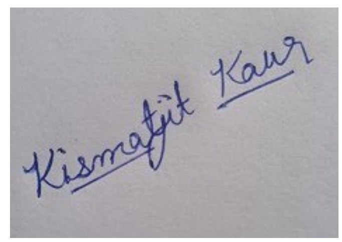
CANDIDATE'S DECLARATION

I hereby declare that the work presented in this thesis entitled, ‘How do Road Users Negotiate Signalised Intersections at Right turns? An Analysis using Social Networks’ submitted in partial fulfilment of requirements for the award the of the degree Master of Arts in Psychology, presented in the Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala, is an authentic record of my work carried out under the supervision and guidance of Dr. Ipsita Chowdhury , Assistant Professor, Thapar School of Liberal Arts & Sciences, Thapar Institute of Engineering and Technology, Patiala and refers other researchers’ work which are duly listed in the reference section.



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The matter embodied in this thesis has not formed the basis for awarding any other degree at this or any other university.

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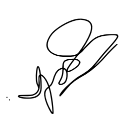

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Abstract

A significant portion of the accidental deaths are caused by collisions at intersections between various types of road users. This study used an on-the-road study paradigm to analyse how drivers, riders of two-wheelers, and pedestrians behaved at intersections using ergonomics approaches and the Social Network Analysis framework. Data collected in the form of verbal protocols from an on-road study of cars, two-wheelers, and pedestrians was used to analyse behaviour at three signalised intersections using social networks. A total number of 36 participants (N = 39) were used in the study. The candidates were chosen randomly and conveniently from ages ranging from 25 to 45. The data collected included 13 car drivers (n = 13), 12 participants who drove a powered two-wheeler (n = 13) and 13 pedestrians (n=13). The analysis identifies occasions when these disparities in behaviour may be causing disputes amongst various road users and demonstrates how they differ among the various road user categories. It is discussed how intersection design contributes to these behavioural variations and the ensuing conflicts. It is concluded that intersections are currently not constructed in a way that encourages behaviour among the three types of road users examined. There is discussion about improvements that can be done to increase intersection safety and make the intersections easier to navigate.

Keywords: intersection, social networks, drivers, two-wheelers, pedestrians

TABLE OF CONTENTS

CHAPTER 1 : INTRODUCTION

ROAD ACCIDENTS IN INDIA:

Every year, a total of 1.3 million people die globally as a result of road accidents. In any country road safety is a developmental problem and a public welfare concern. Road accidents are a major problem in India as India ranks at the top of the world index showing the highest death rate with about 11 percent share of the world (Ministry of Road Transport and Highways, 2022). There are many different types of road users in India and they are bound to have different thinking patterns and behaviours while navigating the road structure. For example, pedestrians usually want to make use of zebra crossings to cross the road which is not always possible due the drivers not stopping their vehicles for the pedestrians to cross. Sometimes, the vendors also block the road. Similarly, auto-rickshaws tend to stop anywhere in the middle of the road to pick up passengers. There are also trucks, buses, cyclists and other vehicles present on the Indian road.

According to the World Health Organisation (2021), at least one out of the 10 people killed on the roads is from India. It was also mentioned in the report presented by the Ministry of Road Transport and Highways, that the worst affected age group in the road accidents was 18-45 years. This included 67 percent of the total road accidents. In India, on an average there are 47 accidents and 18 deaths every hour. This data emphasises the urgent need to take initiative for the prevention of road accidents and resultant consequences.

Road accidents are unwanted by the road users but the frequency of road accidents in India is quite high accounting for about 4.5 lakh crashes per annum. The proportion of people who own vehicles is increasing by leaps and bounds. For example, taking the case of two wheelers it was reported in the Road Transport Year book that India has the greatest number of 2-wheeler registrations worldwide, followed by Indonesia. Also, in a survey report in 2022 , it was mentioned that there are over 21 crore two wheelers and there are above seven crore registered four wheelers and above category as reported by the Ministry of Road Transport and Highways. Globally, accident rates are significantly higher, with 26% of deaths from walkers and cyclists and 28% from two- or three-wheeled vehicles. 29% of those are people in cars, and another 17% are unidentified (WHO, 2018). Moreover, the road structure is being updated and becoming highly complicated under the guidance of modern technology to accommodate these vehicles. Taking the example of different types of roads, we can notice many different categories based on the types of materials used, their function, traffic volume, width as well as topography. Moreover, there are highways, pedestrian ways, cycle tracks, motorways or expressways, arterial roads, freeways, etc all having different rules and regulations for the road users. As the road structure becomes more complicated, the driver may fail to attend to all this information. Also, car drivers find faster roads to be far more tempting, which increases traffic congestion along certain routes. This may also give rise to manoeuvring difficulties. Mack and Rock (1998) have demonstrated that we might be less likely to notice an object when we are staring directly at it than when it is farther out from the centre of our field of vision. So, the road users may not be able to see all traffic signs along the path. Also, in a study by Rataj and Vollrath (2006), drivers perceived intersections with traffic lights to be more strenuous and difficult than those with traffic signs and no signalization.

Many factors can contribute to road accidents. There are many untrained and unqualified vehicle users on the road. However, this is due to the incompetence of the authorities as they are unable to enforce the rules and regulations. There are many people who drive only with a learner's licence or without a valid licence. According to the Ministry of Road Transport and Highways, in the year 2021, there was an increase of 13 percent in accidents caused by drivers with a learner's licence from the year 2020. Another thing to be noted is that while most of the road users are aware of the safety rules and traffic regulations, accidents still occur. In a thorough investigation of traffic safety (Treat et al., 1977), it was discovered that human error was the single cause of 57% of accidents and a contributory factor in more than 90% of them.

Most of the road accidents occur due to human error (Petridou , Moustaki, 2000). We can understand this point by taking an example. While navigating the roads, information is constantly being thrown at people. The majority of the information is received visually from the road, other cars, pedestrians, signs, the passing landscape, etc. Additionally, the driver may be processing information from other sources such as auditory input (listening to the radio, chatting on a cell phone, engaging in conversation with a passenger), internal input (remembering instructions, or deciding what to make for dinner), or other sources of information. The ability to perform all tasks at once may be possible if the visual information flow is modest. However, when attentional needs outweigh supply, the information is of poor quality (bad visibility), the flow becomes torrential (moving quickly), resources must be concentrated on a specific subset of the information (a car close ahead). It may also occur if the driver is too old, using drugs or alcohol, or is too tired. The road user may only use a small subset of information to make decisions and respond while not taking into account all the other information. This creates the possibility for the road users to make mistakes. Because the situation is common and fits into a well-known driving schema, it typically works effectively.

These traffic incidents can also be caused due to different types of perspectives of different road user groups. If a person is unable to understand the viewpoint of the other road user groups and how they navigate the road system, this may cause discrepancy in cognition that can lead to road crashes.For example, the driver's may not correctly perceive the radius of a curve or the speed or proximity of another vehicle. The pedestrians move more freely on the road systems than the drivers and navigate according to the path they want to form. The traffic systems typically span several physical regions, involve a large number of participants, have goals and objectives that aren't always in line with those of the network operator or with those of the participants themselves (e.g., system optimum vs. user optimum), and have a number of primary inputs that are out of the control of both the operator and the participants (e.g., the weather, the number of users, etc.). A road user can only focus on a finite number of occurrences at once. The key to accessing the awareness and selecting the information one finds most fascinating is attention. The road users are constantly exposed to more information than they can possibly digest.

EVALUATION OF INTERSECTION DESIGN IN INDIA:

The improvement of the driving environment is a concern for the safety engineers. Experience has shown that emphasising how people interact with the road environment might be more beneficial. We may learn how to achieve this by looking at the definition of a road accident as follows: "a road crash is a rare, multi-factor event always preceded by a situation in which one or more road users have failed to cope with the road environment, resulting in a vehicle collision." In comparison to other countries' traffic control systems, India has a relatively adaptable traffic system, claims Singh et al. in 2021. In India, there are numerous roads that are still being built and others that are being developed, hence there are far fewer traffic records than in other nations.

Intersections are an important part of the driving environment and a major safety concern for road users. Intersections are points or areas on the road where roads merge or cross each other. Different road users coming from different directions meet at this point which creates a great potential for road accidents or collisions. The vehicles coming from different areas have to share the same space with each other and have the desire to move in different directions. This may create a conflict of interest among different road users which have made it necessary to understand the design of the intersection.

While studying road intersections, there are some general elements of an intersection that need to be kept in mind. Each intersection has some roads extending from it which are called the legs of the intersection.

An intersection may have four legs or three legs depending on its design. The two main legs for any road user are the approach leg and the departure leg. The road from which the road user arrives at the intersection is called the approach leg and the road from which he leaves is called the departure leg. An intersection may have a major street and a minor street. Major streets have a higher functional class because they serve the mobility needs of a higher number of road users and they can carry higher traffic volume while the opposite is true in case of minor streets. It should be noted that major streets have a larger cross-section in contrast to minor streets which have a smaller cross-section.

According to the Central Road Research Institute, the most important thing to be kept in mind is that the number of intersections should be kept minimum. The geometric layout of the intersections is selected in such a way so that harming movements by drivers are eliminated. The design of the intersection is designed in a way that allows the driver to perceive the path he should take with the help of the layout and other things such as traffic signs. This also helps the drivers with the actions of merging with the traffic and diverging from the traffic. The layout of the intersection allows the drivers to follow the natural path that should be taken by the vehicle. The corners must not be abrupt or sharp so as to not cause disruption in the flow of traffic. The number of lanes needed at an intersection is also taken into consideration. According to Mukherjee and Mitra (2019), despite the construction of numerous flyovers to reduce traffic congestion and maintain a smooth flow of vehicles including cars, trucks, high-acceleration bikes, dangerous blue line buses, cycle rickshaws, bicycles, and scooters, Delhi's roads still appear to be narrow. When flyovers are built for large through movements along an arterial, previous studies for homogeneous traffic with lane discipline have shown that the capacity of an intersection can increase by up to 300% (Bonilla, Urbanik, 1987). In India, right-turning vehicle movements are not typically permitted in the area underneath a flyover at the same time. However, this has been made possible in industrialised nations using interchanges like the diamond interchange as well as the single-point urban interchange. The previous options to facilitate this type of movement of road users might not be practical because flyovers in India are built in urban settings with constrained right-of-way. Alternative intersection designs that can effectively manage Indian traffic have not yet been researched in these circumstances.

Channelization is a concept which has not yet fully come into use in India. Channelization means that in order to promote the safe and orderly flow of both automobiles and pedestrians, it is the separation or regulation of conflicting traffic movements into distinct lanes of travel by traffic islands or pavement marking. A raised channelizing island can be installed or painted markings can be used to provide channelization. Several justifications are provided in the AASHTO (American Association of State Highway and Transportation Officials) Policy on Geometric Design of Highways and Streets for considering channelization at an intersection. There should be no more than two vehicle paths that cross at any given location due to restrictions on vehicle paths. There are some movements which merge, diverge, or weave the road user in the traffic at specific angles. These movements may be controlled. It may be possible to lower the amount of pavement, which would lessen the propensity to wander and reduce the area of conflict between vehicle tracks. The proper vehicle paths may be more clearly shown in the area of the intersection so that there is no confusion among the drivers. It's possible to give emphasis to dominant movements of the road users. There may be places for pedestrians to take refuge so that they can wait out of the way of vehicle users which may reduce attention division of the vehicle users. In order to allow turning cars to wait clear of through lanes, separate storage lanes may be offered. There may be room to deploy traffic control equipment in more obvious places. It is possible to physically regulate forbidden tums. Vehicle speeds can be a little slower.

In India, the flow of left-turning traffic is either merged with the phase of straight traffic movement or is not affected by traffic signals at all. Since there is no traffic in either situation to impede their movements, turning left is a relatively simple manoeuvre that is considered safe. Right turning actions, however, provide certain challenges. When making a right turn at a junction, a driver must pay attention to multiple moving traffic elements at once, including oncoming vehicles, traffic signals, and pedestrians who are crossing the street (Lord, 1996). It's been noted that on the majority of occasions, road users are unable to anticipate the manoeuvring course of right turners and a serious conflict situation results. Therefore, it is almost always preferable to create a channelized road for right-turning cars where there is room available. This is particularly true at signalised crossings, where the two main advantages of such channelization are: Channelized right turns reduce the possibility of a right-turning vehicle or vehicles being stranded behind a through vehicle in a shared lane where "right-turn on red" laws are in place. Right turns when channelized can be successfully removed from the signalization design since they are often regulated by a YIELD sign and the road users are allowed to travel constantly. But certain channelization design specifics are necessary for these benefits to be realised.

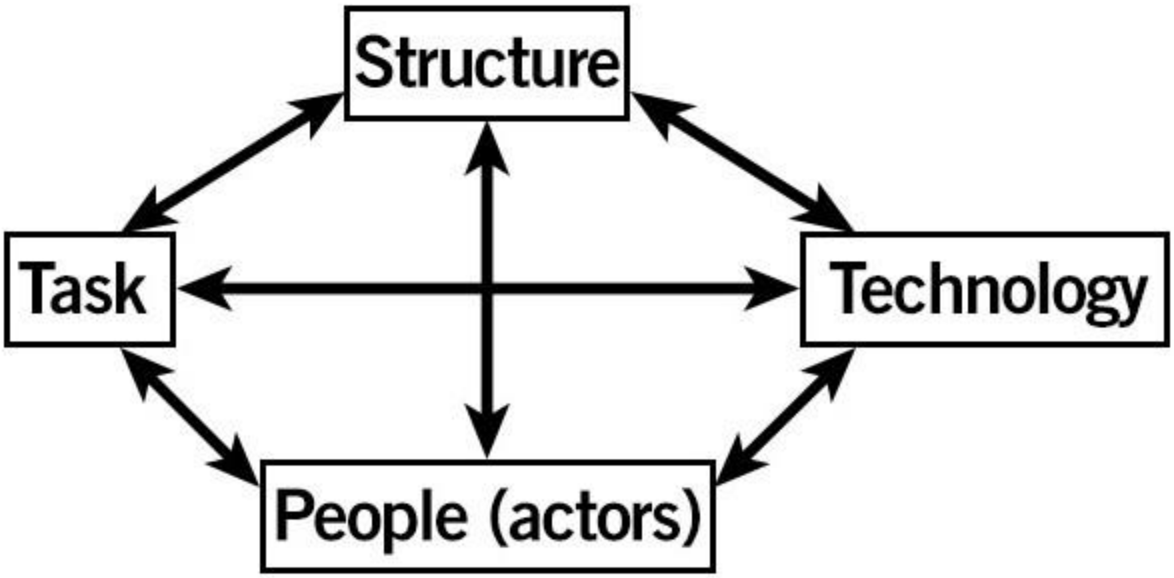
Recently, traffic sign detection and identification have become more responsive, which is crucial for the improved driver support systems of autonomous vehicles (Avramovic et al., 2020). In India not all the roads are properly signalised. Many road users are still unable to identify traffic signs which is a major problem. Another sort of road hazard is a pothole. It might be a road structural fault that has an arbitrary shape and is mostly composed of tiny, bowl-shaped cracks in the road's surface. The lives of people are seriously endangered by potholes. A challenging object-recognition exam includes the identification of a pothole, an arbitrary form, and a complex geometric pattern (Satti et al., 2021).

ROAD NETWORK AS A SOCIOTECHNICAL SYSTEM:

The word sociotechnical is formed by combining two words meaning ‘socio’ which means of the people and society and ‘technical’ which means related to machines and technology. The term ‘socio-technical’ describes how "social" and "technical" are interrelated. Individuals engage in socio-technical interactions with (a) technologies and (b) other people. The fundamental tenet of socio-technical theory is that ‘social' and 'technical' aspects of any organisational structure can only be understood and improved if they are combined and handled as interdependent components of a complex system.

A specific manifestation of sociotechnical theory, a sociotechnical "system" is the word used to describe any real instance of socio and technical elements engaging in intentional goal-directed action. In order to describe, analyse, and create systems with joint optimization in mind, sociotechnical systems adopt the ideas and metaphors of general systems theory, particularly the idea of "open systems" (e.g. Bertalanffy, 1950). These systems, in particular, embody some degree of non-linearity both within themselves and in the environment they live in. This means that there are some unpredictable cause-effect relationships in a system that are unpredictable and may not be normally designed. The goal is to understand these relationships so as to bring harmony in a system so that it functions more effectively. This can be done by studying both the actors (people) in the system and the technological aspects of the system. The management and the maintenance of these relationships is also important. From the perspective of psychology, the main use of studying the sociotechnical system is to understand the acceptance of technology by the actors in a system. These actors are sometimes studied as a group at the meso-level which offers a way to analyse the functionality of actors at individual level factors (e.g. Fielding et al. 2008).

The work of Harold J. Leavitt (1965), who believed that organisations were made up of four interdependent variables—task, structure, technology, and people (actors). If you changed one of them, the other components would change in a way that was compensatory and regulated. Technologies are instruments that assist organisations in carrying out their duties and assist processes in converting inputs into outputs. Since it affects organisational structure and technology as well as knowledge work processes and people, knowledge management is more than merely managing those things. According to the viewpoint taken by this framework, it is only possible to illustrate the activities of knowledge management in an organisation when the balance of all four variables is taken into account. The following diagram illustrates these four variables in the form of a hexagon.



Any organisation, or a component of it, is made up of a collection of many different interdependent subsystems from the standpoint of socio-technical systems. The interconnectedness of transportation systems and the global challenges call for innovative approaches to strategic planning, system-level thinking, and decision-making. The road intersections are also a sub-systems of the larger transportation sociotechnical system. The achievement of essential intersecting functions, such as to minimise collisions, maximise efficiency, maximise compliance, optimise flexibility, and be mindful of user preferences, is crucial for conforming to sociotechnical systems ideals. This can be done by improving and regulating the four variables shown in the above diagram. While navigating the roads and the intersections the different road users perform different tasks like deciding the path by which they overtake the other road users or cross the intersection. The performance and efficiency of the road users while performing these tasks in a way which does not interfere with the other road users and how they interact with the technology is also important. The structure of the system which here refers to the road and intersection infrastructure affects the performance of the road users. This structure needs constant maintenance and improvement to cater to the needs of its users. The actors should have proper knowledge of the tasks needed to be performed, the structure as well as the structure. The road users can be trained to think or behave in ways that provide better understanding of workings of the other groups or be provided with proper knowledge about the infrastructure like road signs to optimise the system.

CHAPTER 2: LITERATURE REVIEW

In the present scenario, research is being done to understand the behaviour and cognition of different road user groups while navigating the road traffic system in order to make improvements in system design and avoid any road accidents. Intersections are a major part of this system and areas more prone to collisions. In this study, we have focused on the road intersections.

In a study by Abhinav Kumar, Madhumita Paul and Indrajit Ghosh (2018), analysis of pedestrian conflicts with Right-Turning Vehicles at signalised intersections in India has been done. The study showed different behaviours of road users in context of the conflicts occurring between pedestrians and other vehicle users. The study was conducted in four cities of Delhi and Kolkata. Four levels of severity levels gave the range of the three conflict indicators. It was seen that the severity of conflicts of pedestrians with different types of road users varied according to vehicle type. The highest level conflicts occurred with cars and SUVs. Due to their slower speeds at crossings and the behaviour of pedestrians after recognizing such (large-sized) vehicles, heavy vehicles exhibited the least severity.

The study by Weinreuter et. al., 2022 showed the influence of intersection complexity on human drivers. Several characteristics were examined using the intersection complexity, which were represented by the features extracted from the data set. The researchers looked into how the entry location and turning direction at intersections affect driving behaviour. Additionally, they also considered how to forecast a driver's behaviour as well as how the characteristics that make up an intersection's complexity affect it. The findings demonstrated that a human driver's conduct is significantly influenced by the desired turning direction through a junction.

The attentional requirements on cyclists and drivers in urban intersections were studied by Katja Kircher and Christer Ahlström in 2022. In the same intersection, the number of necessary minimum attention needs was either higher or equal for vehicles and bikes. In every intersection, there were practical minimal attention standards for bicycles, but there were none for drivers. It was seen that the current infrastructure is designed to exclude cycling in favour of motorised cars. The findings also show that explicit requirements, as defined by infrastructure features, are more frequently met than implicit requirements.

In a study by Paul M. Salmon, Michael G. Lenne, Guy H. Walker, Neville A. Stanton and Ashleigh Filtness (2014), the conflicts between various road user groups when performing right-hand turns at urban crossroads were investigated. The road users were driver, cyclist, motorcyclist and pedestrian. Analysis was done by making task networks, social networks and situational awareness networks. The results showed there was a significant level of differences in the behaviour of road users in the intersections studied. The different road user groups had differentiated in the type of tasks they performed while navigating the intersection and had different types of situational awareness. The results also showed that the way the intersection is designed may cause conflict between different road user groups.

CHAPTER 3: RESEARCH GAP, MOTIVATION AND OBJECTIVES

RESEARCH GAP:

The previous research work has focused more on the air and water traffic systems but the research related to the road infrastructure and human interaction is a recent development and has not been studied to a great extent. In the research related to the road users and the road traffic infrastructure a reductionist approach has been taken. The available studies focus mostly on an individual road user group and not the many different road user groups as a whole. However, in this paper, three different road user groups have been studied simultaneously and comparatively in a single operational system. This study is an effort to explore the direction of relationships between different road user groups. Moreover, there is a plethora of studies such as that pertaining to the western population. Not enough studies have been previously available to prove the credibility of road user differences in perspectives, thinking and behaviour in Indian context. Another thing to be noted is that almost all of the previous studies have been done by using a stimulator or by using video analysis techniques from the traffic cameras. There is an insufficiency in literature that follows an on-road paradigm. In this we have studied the behaviour of different road user groups with the help of an on-road paradigm while making use of video and audio equipment for analysis purposes. This study also aimed to reduce the insufficiency that exists in literature in Indian context.

MOTIVATION OF THE STUDY:

The study was aimed at simultaneously examining the behaviour of three different role user groups that included card drivers, two wheelers and pedestrians while crossing three intersections; there is particularly dearth of literature on examining these user groups at a single time. Modifications have been made for improving the design of vehicles but these modifications depend on whether the users are actually accepting them. This study has been done to test such human factors. Moreover, road safety has been a rising concern of our country. The intersections are complicated road structures which need to be more closely examined to avoid road accidents. Also, such studies allow us to understand human errors made while driving. There is a need for more studies to decrease the number of collisions that occur due to differences in the behaviour of different road user groups.

OBJECTIVES:

- To examine if systemic methods can be applied to study a heterogeneous traffic environment.
- To identify differences in behaviour across different forms of road users when negotiating the three intersections.
- To identify factors that may play a role in conflicts between different road users at intersections while executing right turns.
- To take into account the intersection design and the problems related to the intersection design.

CHAPTER 4: METHODOLOGY:

SAMPLE:

A total number of 36 participants (N = 39) (mean = 36.71) were used in the study. The mean age of the participants is 36.71 and the standard deviation is 5.179. The number of males who participated in the study is 22 and for females is 17. The candidates were chosen randomly and conveniently from ages ranging from 25 to 45. The participants were chosen from different types of working spheres of Patiala like school teachers from Old Police Line school and Multipurpose school, Education department, employees of Architecture department of Punjab, employees of Municipal Corporation and some business owners. The sample included three different road user groups. The data collected included 13 car drivers (n = 13) (mean = 38.30, S.D. = 4.02) , 13 participants who drove a powered two-wheeler (n = 13) (mean = 36.53, S.D. = 5.18) and 13 pedestrians (n=13) (mean = 35.30, S.D. = 6.33).

The inclusion criteria for candidates to participate in this study was that the participants were living in Patiala for the past five years. The participants were to have a valid driving licence. All the participants had no records of any major accident.

RESEARCH DESIGN:

This study used an on-road study paradigm in which the participants negotiated a pre-defined 4 kilometre urban route Here, an on-road study design is used to get real time data and to create similar conditions as the subjects face in their everyday life. Verbal protocols are a ‘think aloud’ method in which the subject gives descriptions of the physical activity and the descriptions of his thoughts or cognition while performing a specific task. Verbal protocols training were provided to the subjects so that only the information relevant to the experiment can be received. The comments regarding the weather or any personal information were not to be spoken. The route comprises a mix of different road environments like a market area, an environment park area, a bus stand area and a flyover. Bikers, cars and pedestrians drove their own vehicles while the experimenter was sitting at the back of the vehicle using the audio and video recording equipment to record their videos and verbal protocols. Drivers navigated the route while driving their own vehicles. The three intersections were crossed by pedestrians while donning video recording instruments at the front and audio was recorded using a dictaphone. As they navigated the route, each participant described their thoughts and actions out loud. The route navigated by the participants is highlighted in the picture shown below. The experiment was conducted at off peak hours of traffic from 12 pm to 4 pm.

TOOLS USED:

A triple rear camera of 50 Megapixels of a mobile phone (Samsung Galaxy A14) was used to accumulate video recordings of the participants while they were driving. A Sony ICD-PX470 Dictaphone was used to record the audio of the candidates of the study. Microsoft Word was used to transcribe the verbal protocols of the participants. NVivo is a tool used for transcribing the verbal data and analysing it using codes, cases and queries. It has been used to allocate codes to different agents in the environment which interacted with the participants and also used to add references which describe the context in which the participants mentioned the agent. Gephi was then used to make social networks.

STUDY ROUTE:

A 4 kilometre urban route near the Thapar University campus was used for the on-road study component. The route consisted of a mix of different types of areas or sections like the market area, the environment park area, a bus stand area and a flyover. The route had many intersections and T points but only three intersections were used for the analysis component. All the three intersections were fully signalised.The road along the route from Thapar intersection to the Gurdwara intersection is known as the Jail road which is a divided road having a width of 27.43 metres. The width of the carriageway (meaning the path along which the vehicle can move unobstructed) along this road is 7.30 metres. Similarly, the road from Gurdwara intersection to the bus stand is a divided road having a width of 18.29 metres and the width of carriageway is 6.71 metres. There were three right turns and one left turn along the route. There was also a flyover in the route which had a length of 650 metres. There was also a roundabout but the participants didn’t come in direct contact with it as it was located peripheral to the intersection. There were no dedicated lanes provided for bikers along any of the intersections and there were no dedicated structures provided for the pedestrians. The picture below highlights the study route. In the highlighted route, the black dots represent the three intersections studied in this study.

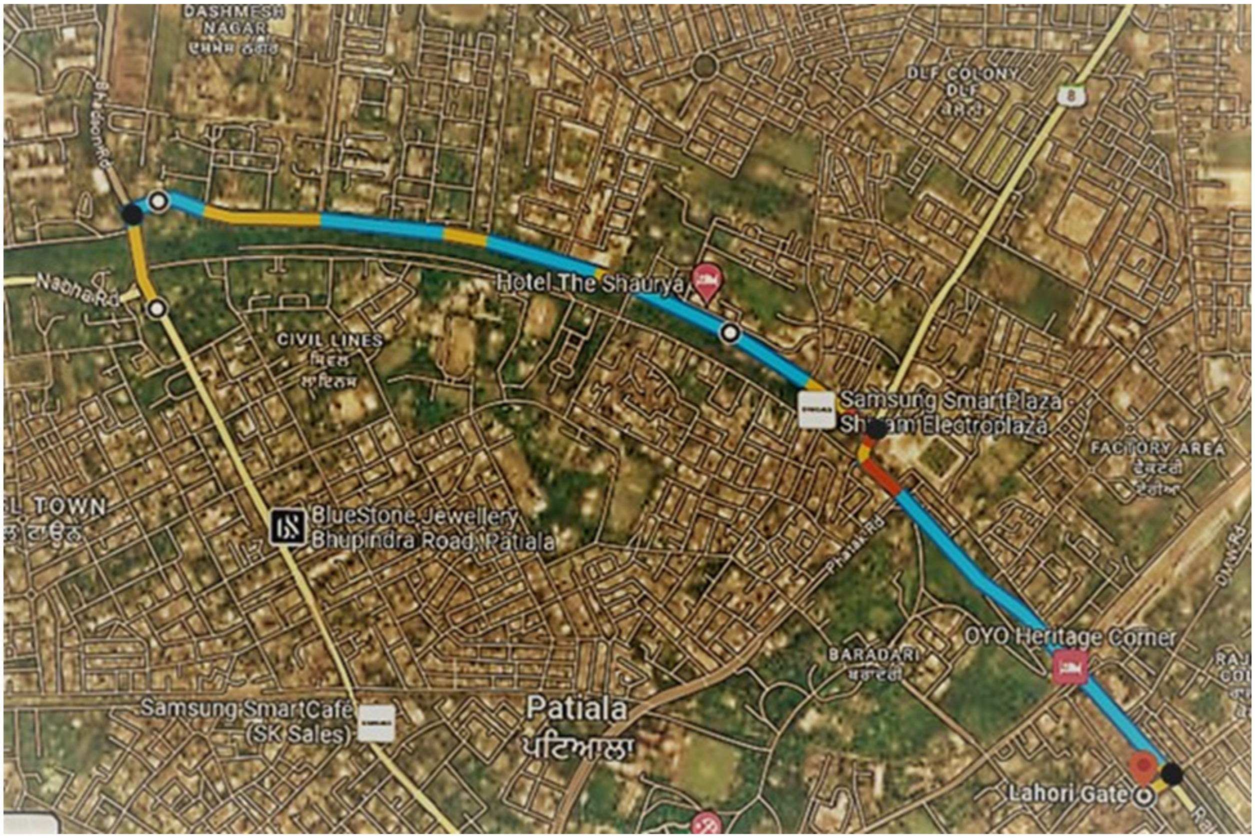


Figure 1 shows the route taken by the participants highlighted in blue with black dots on the route showing the positions of the intersections.

The intersections are shown in more detail in the pictures shown below. The white arrows show the right turns taken at the intersections by the subjects. The first two intersections are skewed T-intersections while the third intersection is a four-leg intersection. The third intersection is connected to a flyover on one side and includes two traffic islands.

Figure 2 shows Intersection 1: Thapar intersection.

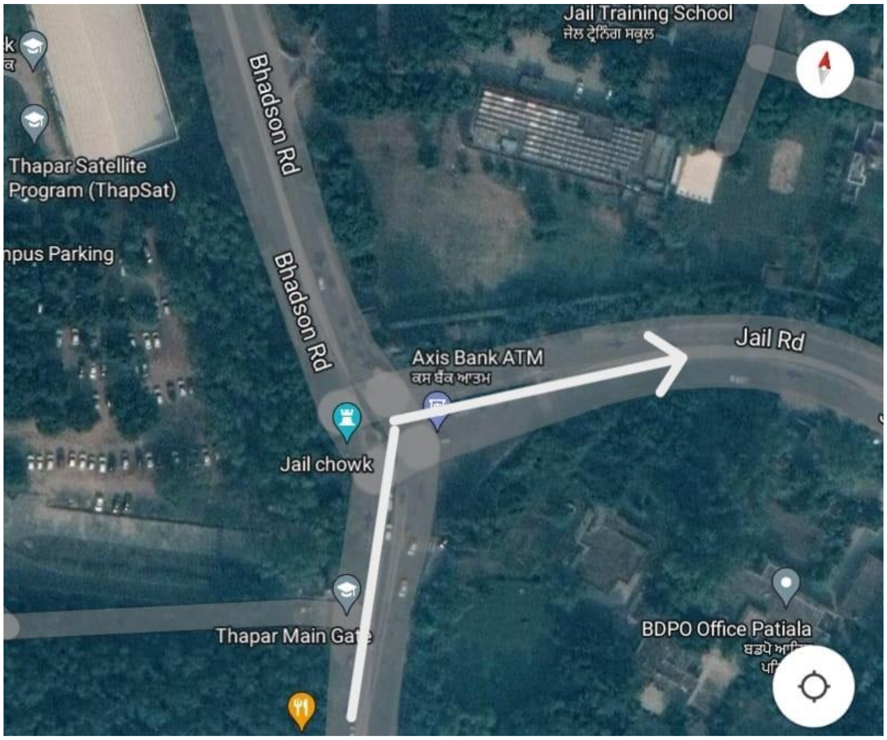


Figure 3 shows Intersection 2: Gurdwara intersection.

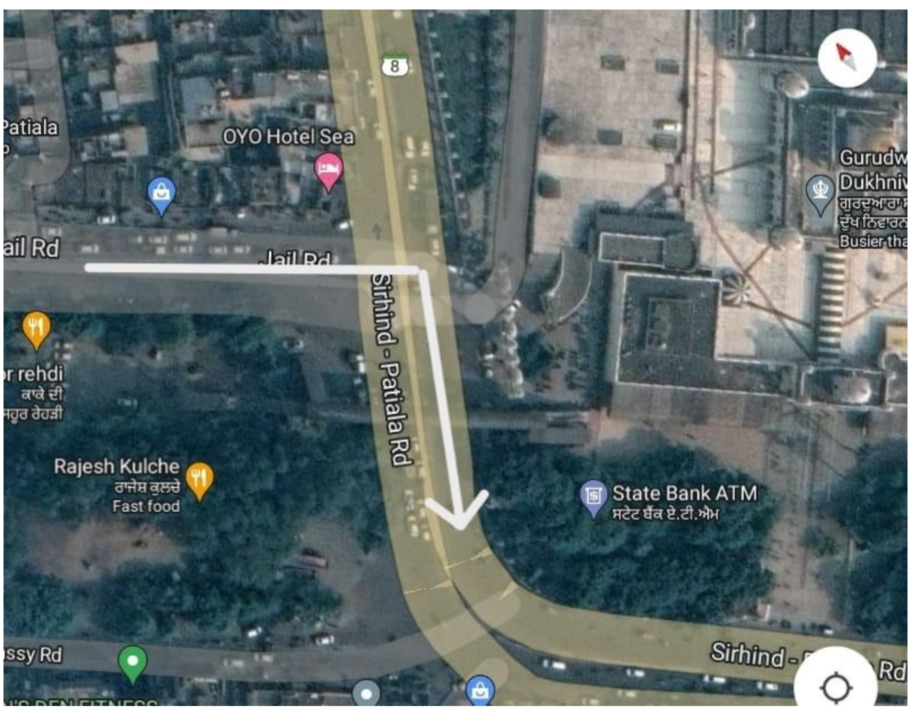
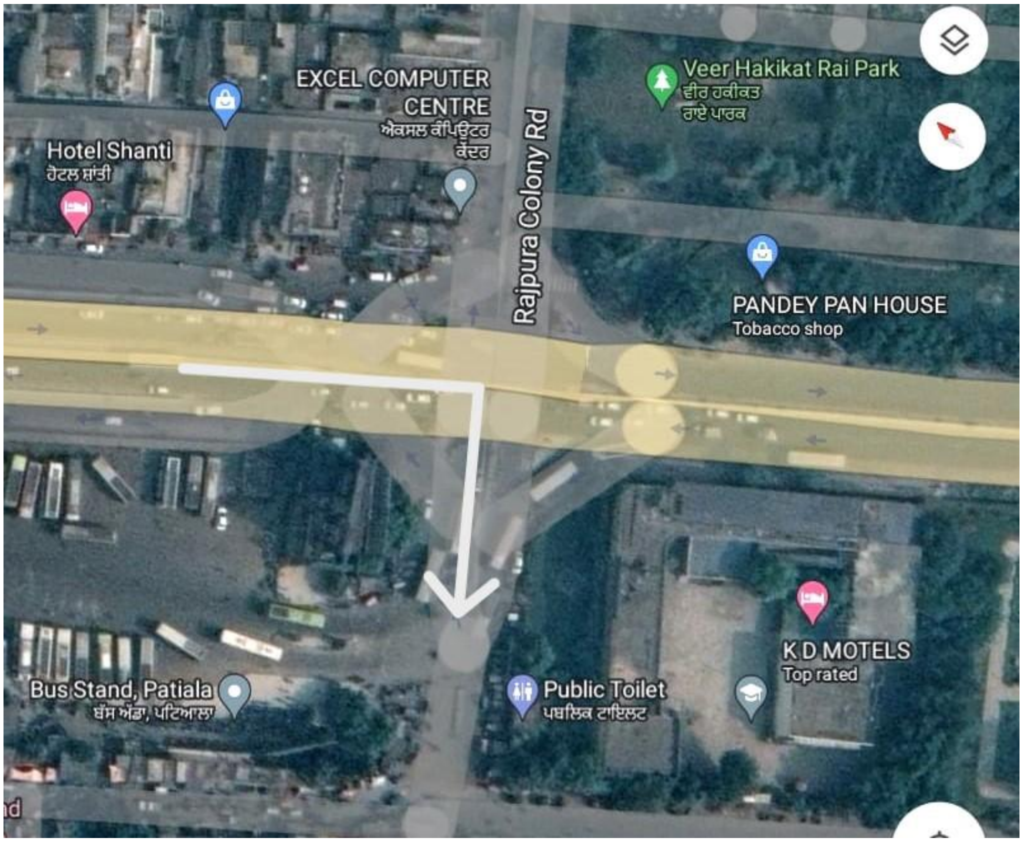


Figure 4 shows Intersection 3: Bus stand intersection.



PROCEDURE:

The intersections were dealt with separately by each participant. All testing was conducted on weekdays at the same predetermined hours to account for traffic circumstances. Participants first completed the informed consent form and demographic questionnaire and were then briefed on the research and its aims. Following this, they were given training in providing verbal protocols which included instruction from an experimenter followed by a video presentation in which verbal protocols were provided. Further, the participants were shown a list of different verbal protocols. For example, "I am noticing the traffic lights.", "There is a car in front of me.", " There is a dog on the road.", etc. The subjects were also told that they should speak about things relevant to the experiment while following the verbal protocols and not about any personal information. They were told to 'think aloud'.

The subjects were then given training on a different route so that they could practise what they should and shouldn't do. After the experimenter was satisfied with their performance, the subjects were asked to get ready for the experiment. The subjects were asked to reach the starting point of the experiment. The video and audio equipment was then set up. The subjects were also told about the route that they had to take. They were shown the route through google maps. Once they confirmed that they had understood the route, the experiment was started.

The experimenter sat in the passenger seat of the car while the drivers navigated the predetermined route and provided assistance when necessary and in some cases also prompted the driver to speak. In case of the powered two wheelers, the experimenter sat on the back of the vehicle while in case of the pedestrians, the experimenter walked alongside the subjects while they navigated different intersections. Also, the pedestrians were driven to the intersections they had to cross by the experimenter.

CHAPTER 5: RESULTS

TABLE NO. 1 shows the demographics of the participants.

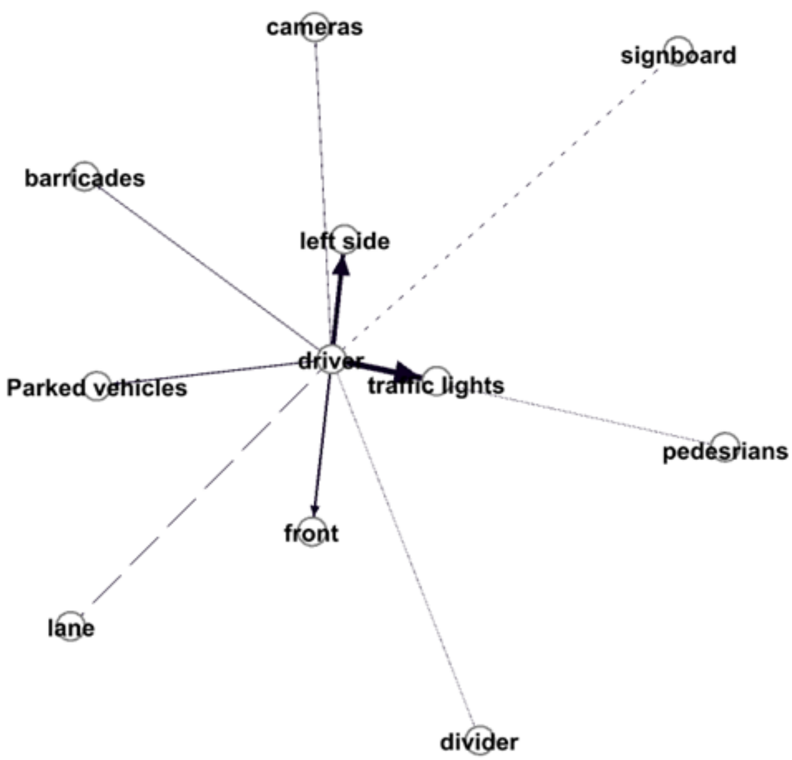
Road user group	Mean (age)	Standard deviation	Gender	Number of participants with previous experience of each intersection in the 2 weeks before the experiment.		
Drivers	38.30	4.02	6 males, 7 females	8	9	8
Two-wheelers	36.53	5.18	6 males, 7 females	6	5	7
Pedestrians	35.30	6.33	10 males, 3 females	9	6	9

The first table shows the demographics of the participants. The mean age of the participants is 38.30 for drivers. The mean age for two-wheelers and pedestrians is 36.53 and 35.30 respectively. The total number of males and females are 22 and 17 respectively. The number of participants with previous experience of each intersection in the 2 weeks before the experiment are shown. In the case of the first intersection, 8 drivers, 6 two-wheelers and and 9 pedestrians had previous experience 2 weeks before the experiment.

The social networks show how the different road users interacted with different intersections. These networks show the interaction of each road user group with the other road users, the environment of the intersection and the road infrastructure. For example, if the participant says, “I noticed the traffic lights” then this is considered one interaction with the traffic lights. Similarly, the interaction with the other parts of the intersection is shown in the form of the nodes which represent different agents of the intersection system like traffic lights, cameras, footpaths, etc. The thickness of the arrows directed towards different nodes depicts the frequency of interactions or relationships with distinct road users or other things in the environment. The thicker the arrows the higher is the frequency of interactions with a particular part of the intersection.

INTERSECTION 1: The results of the drivers, two wheelers and pedestrians at the Thapar intersection are shown below.

FIGURE 1 shows the social network of the driver road user group at intersection 1.



FIGURES 2 shows the social network of the two wheeler driver user group at intersection 1.

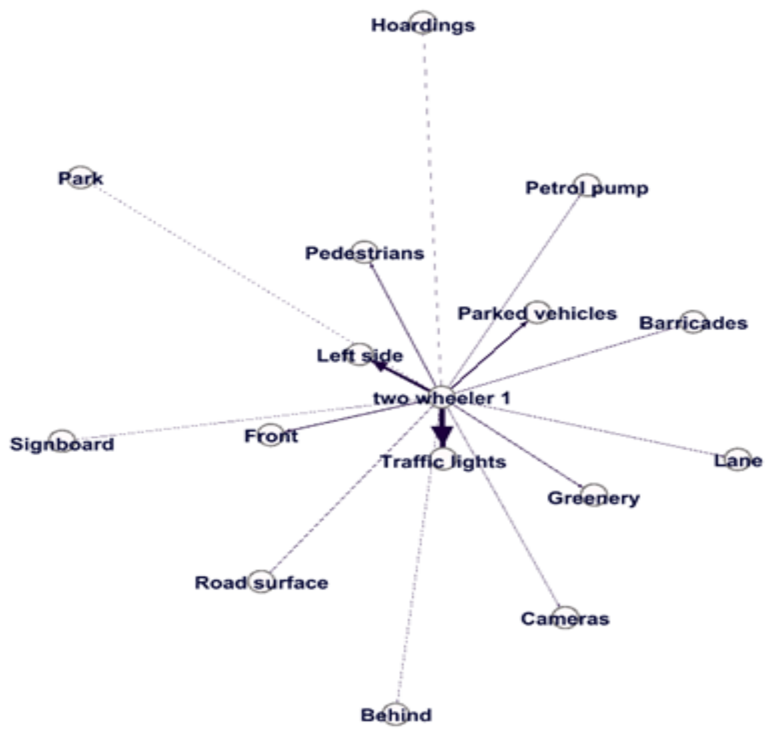
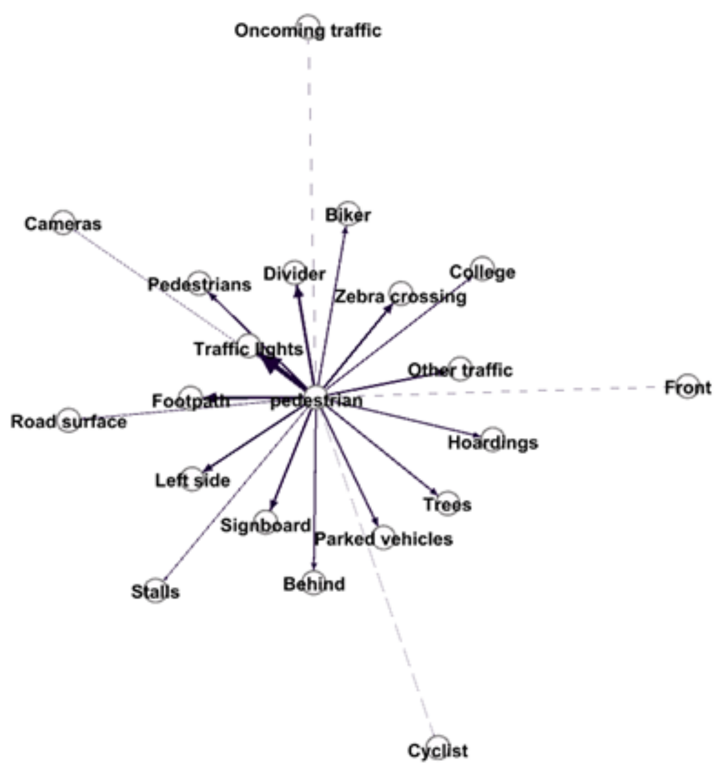


FIGURE 3 shows the social network of the pedestrian user group at intersection 1



The above networks show the interactions of the road users at intersection 1. It can be seen through the network that the highest number of nodes belong to the network with the pedestrians followed by the two-wheelers and then drivers. The highest number of interactions in case of all the road users are with the traffic lights. It was also noticed that in case of the drivers and two wheelers the second highest frequency is that of the left side of the road. The second highest frequency among the pedestrians is that of the footpath. In case of the drivers the node signboard has the lowest amount of frequency. The two-wheelers and the drivers have a similar interaction with signboard nodes and have a frequency of 4. The pedestrians had a higher number of interactions with the signboard node which was 11. The drivers and two wheelers have an interaction with the road surface while the drivers had no interaction with the road surface. The traffic cameras were noticed by all three user groups. The car drivers and two-wheelers had a higher interaction with the agents in front of them in the environment while the attention was directed more to the behind. All three of the road user groups had an interaction with the other pedestrians. Only the pedestrians had an interaction with the cyclists.

TABLE NO. 2 shows the summary of social network analysis of intersection 1.

Road user group	Number of nodes	Number of interactions	Density	Sociometric status of road user	Nodes with highest sociometric status
Driver	10	134	0.090	13.40	Traffic lights, left side, front, parked vehicles
Two-wheeler	15	175	0.062	11.66	Traffic lights, left side, parked vehicles
pedestrian	20	306	0.047	15.75	Traffic lights, footpath, divider, ,zebra crossing

The above table shows the number of nodes, the total number of the interactions and sociometric status of each of the three road user groups of intersection 1. The density of the network and the nodes with the highest socioeconomic status are also shown. The sociometric status shows the connectedness of the road user group with the parts of the intersection system and gives an indication of the relatively busy an individual agent is as a communicator with others in the network. The pedestrians have the highest sociometric status with the highest number of interactions. The lowest sociometric status is that of the two wheelers at 11.66 with the number of interactions between those of drivers and pedestrians. The drivers have the lowest number of interactions but the sociometric status is higher than that of the two wheelers. The density of the network shows whether the transmission of information is being done efficiently among all the nodes of the network. It can be seen that the network of the drivers have the highest density, followed by the two- wheelers. The pedestrian social networks have the lowest density. The pedestrians had the highest information flow but that flow is not consistent. The nodes with highest sociometric status can also be seen among the three road users groups. It can be seen that while the drivers and the two wheelers pay the highest attention to the traffic lights, the front and the parked vehicles, the pedestrians pay more attention to the traffic lights, footpath, divider and the zebra crossing.

INTERSECTION 2: The results of the drivers, two wheelers and pedestrians at the Gurdwara intersection are shown below.

FIGURE 4 shows the social network of the driver user group at intersection 2

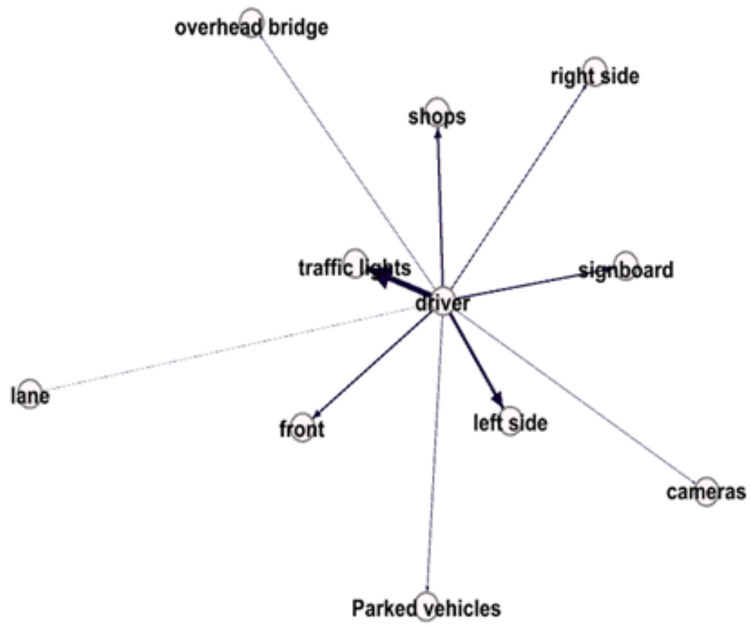


FIGURE 5 shows the social network of the two wheeler driver user group at intersection 2

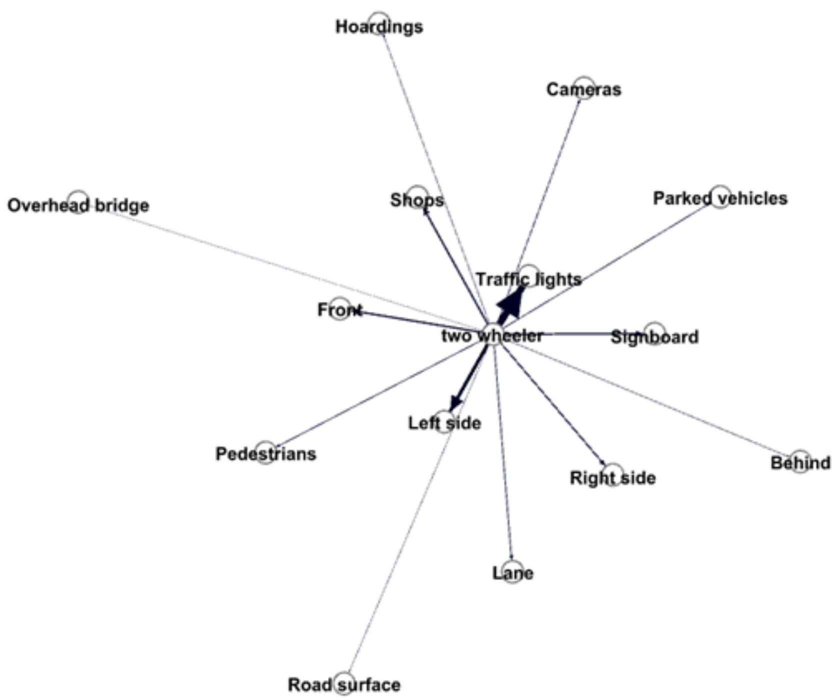
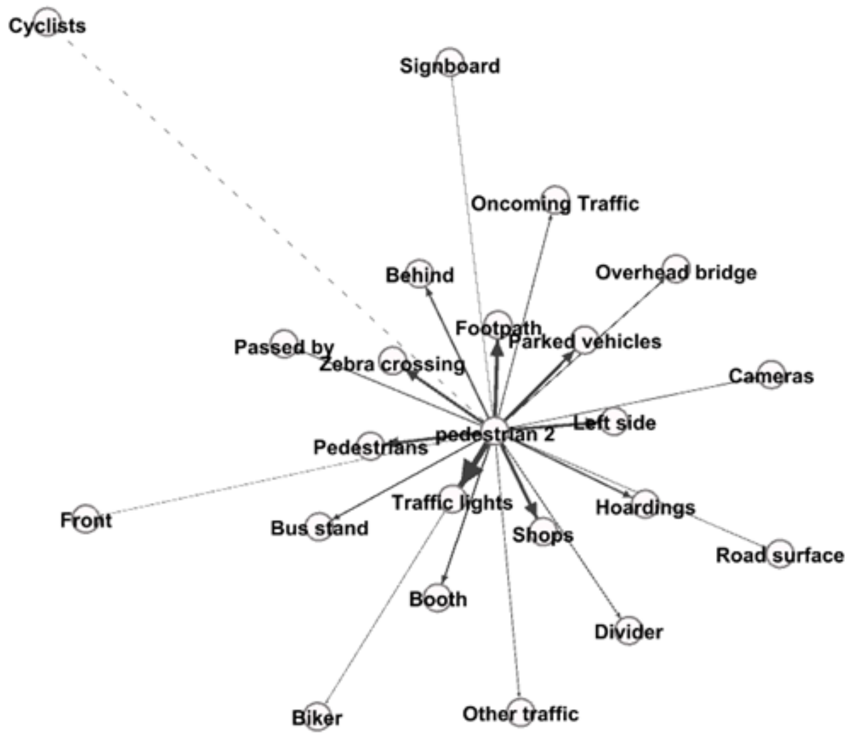


FIGURE 6 shows the social network of the pedestrian user group at intersection 2



The above networks show the interactions of the road users at intersection 2. Again, it can be seen that the pedestrians had the highest number of interactions followed by the two-wheelers and then drivers. The node with the highest frequency among all the three road user groups was traffic lights. Among the driver's, the left side was the node with the second highest number of interactions. In case of pedestrians the second highest frequency was of the footpath followed closely by the shops.The frequency of paying attention to the signboards is more for the drivers and the two wheelers whereas the pedestrians did not pay much attention. The drivers had interactions with vehicles in front of them. The two wheelers had higher interactions with vehicles in front than the traffic behind them. The pedestrians interacted very closely with the parked vehicles as they had to work around them while walking. The drivers and two wheelers had comparatively low frequencies with the parked vehicles node. Only the pedestrians had an interaction with the cyclists.

TABLE NO. 3 shows the summary of social network analysis of intersection 2.

Road user group	Number of nodes	Number of interactions	Density	Sociometric status of road user	Nodes with highest sociometric status
Driver	10	148	0.090	14.80	Traffic lights, left side, shops, front
Two-wheeler	14	181	0.066	12.92	Traffic lights, front, shops, signboard
pedestrian	22	343	0.043	15.59	Traffic lights, footpath, shops

The above table shows the number of nodes, the total number of the interactions and sociometric status of each of the three road user groups of intersection 2. The density of the network and the nodes with the highest socioeconomic status are also shown. The total number of interactions are the highest for pedestrians and the lowest for drivers while the two wheelers are in the middle. The sociometric status of the pedestrians is the highest in the second intersection. The driver has a lower sociometric status than that of the pedestrians at 14.80. The difference between the sociometric status of the driver and two wheelers is higher with two wheelers having the lowest sociometric status. The density of the driver's networks is the highest while the density for the pedestrians is the lowest. Therefore, the consistency of information flow is the lowest among the pedestrians at intersection 2. The drivers have the lowest number of interactions but the information flow was efficient. At this intersection, the nodes with highest sociometric status for drivers are traffic lights, left side, shops and front. The pedestrians have the highest sociometric nodes like traffic lights, footpaths and shops.

INTERSECTION 3: The results of the drivers, two wheelers and pedestrians at the Bus stand intersection are shown below.

FIGURE 7 shows the social network of the driver user group at intersection 3.

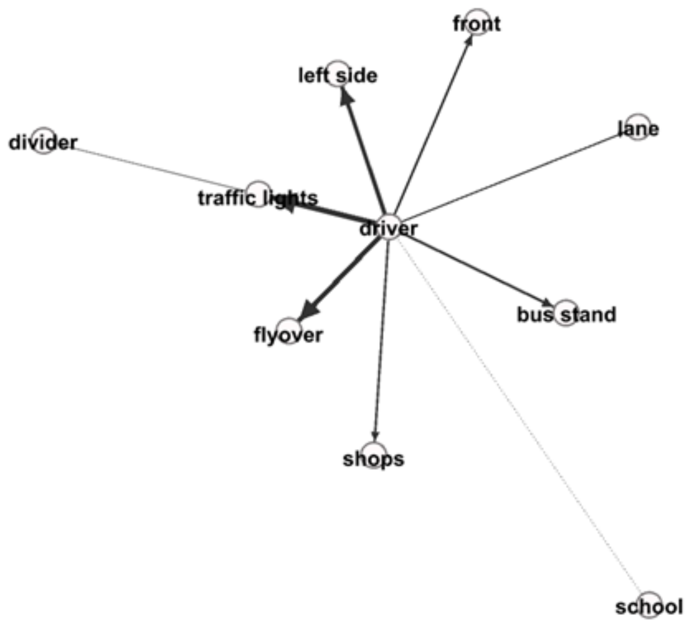


FIGURE 8 shows the social network of the two wheeler driver user group at intersection 3.

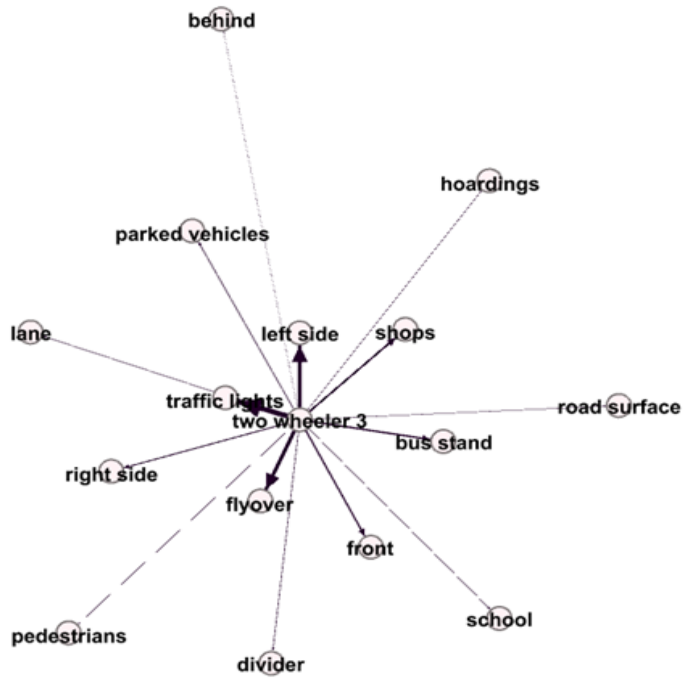


FIGURE 9 shows the social network of the pedestrian user group at intersection 3.

The above networks show the interactions of the road users at intersection 3. The pedestrians have the highest number of nodes followed by the two-wheelers. The drivers have the lowest number of nodes. This means that the drivers interacted less with different parts of the intersection. The traffic lights are the node with the highest number of frequencies among all three road user groups. The node with the second highest frequency for drivers is the flyover for the drivers. In the case of pedestrians, the second highest node is the zebra crossing. The drivers have interacted with the left side of the road while the two wheelers and the pedestrians interacted with both the left side of the and the right side of the road. The drivers didn't have any interaction with the surface of the road. Meanwhile the two-wheelers and the pedestrians faced obstacles on the road surface. Only the pedestrians had an interaction with the cyclists. The pedestrians also interacted with the traffic island.

TABLE NO. 4 shows the summary of social network analysis of intersection 3.

Road user group	Number of nodes	Number of interactions	Density	Sociometric status of road user	Nodes with highest sociometric status
Driver	9	159	0.081	15.90	Traffic light, flyover, left side, bus stand
Two-wheeler	15	204	0.062	13.60	Traffic lights, left side, flyover, shops
pedestrian	21	326	0.045	15.33	Traffic lights, zebra crossing, divider

The above table shows the number of nodes, the total number of the interactions and sociometric status of each of the three road user groups of intersection 3. The density of the network and the nodes with the highest socioeconomic status are also shown. The total number of interactions are the highest for pedestrians and the lowest for drivers. The number of nodes for each road user group are also mentioned. The sociometric status is the highest for the drivers which is very closely followed by the pedestrians. The two-wheelers have the lowest sociometric status among all the road users. This means that the two wheelers have less connectedness with the parts of the intersection. The network of drivers is observed to have the highest density, followed by two-wheelers. The least dense social networks are those used by pedestrians. The flow of information is more consistent among the drivers and least consistent among pedestrians. The nodes of road user groups with the highest sociometric status are also mentioned.

CHAPTER 6: DISCUSSION

The aim of this article was to study the differences in the behaviours of different road users and how their incompatibilities may arise while navigating three intersections in Patiala with the help of social network analysis.

The analysis shows that there were differences in the behaviour of the drivers, two-wheelers and pedestrians while navigating each intersection. It showed how each road user group interacted differently with the environment of intersection which included other road user groups and the intersection infrastructure. All the car drivers had a limited interaction with various parts of the intersection in comparison to the two wheelers and the pedestrians. The pedestrians had the highest interaction with the different parts of the intersection. It was also noted that the drivers had the highest density at all of the intersection which means that while the drivers had the least interaction with the parts of the intersection but the information flow was consistent among all the car drivers in the driver road user group. The pedestrians were the road user group that had the highest number of interactions with the parts of the intersection but the information flow was inconsistent. However, the two- wheelers had a moderate number of interactions and the flow of information was only moderately consistent.

All the road user groups gave paramount importance to the traffic lights and had the highest number of interactions with traffic lights. The drivers paid more attention to the left side of the road and the only interaction with the right side was while referring to major landmarks like the bus stand at the third intersection. The two-wheelers and the pedestrians had interaction with both the right side and the left side of the intersection. The drivers also had more interaction with the parts of the intersection in front of them as compared to the parts of the intersection behind them. At the first intersection, car drivers had a limited interaction with the ‘speed limit’ signboard and the ‘no parking’ signboard at the intersection. This may be due to the improper placement and lack of maintenance of the signboards at the intersection. The signboards were placed at the remote part of the intersection while not being properly visible or blocked by trees. The concept of lanes exists for both the drivers and the two wheelers.

The pedestrians gave more importance to the parts of the intersection such as the zebra crossing, the footpath and the traffic islands. Meanwhile, only the pedestrians had any kind of interaction with one other road user group which are cyclists. This means only the pedestrians paid any kind of attention to the movements of the cyclists and the cyclists did not in any way factor into the decision making of drivers or two wheelers while navigating the intersection. This may be a good sign but for the fact that the intersection did not have any separate lanes for the cyclists that provides an isolated path free from the interference of other road users to cross the intersections.

It was also observed that different road user groups had different ways to navigate the intersection. The car drivers followed the naturalistic path made possible by the intersection design. The drivers either crossed the zebra line while waiting on the intersection or waited on the zebra line which inhibits the pedestrians. The two wheelers moved far more freely while manoeuvring between different vehicles on the road. The pedestrians were the ones who moved the most freely while navigating and had a range of ways for crossing the intersection and made their own paths.

From the above results, it can be seen that this method was successful in studying all the road user groups present in the traffic environment. The method is reliable and applicable to conduct research on the behaviour of different road users. The second objective was to identify differences in behaviour across different forms of road users when negotiating the three intersections. As discussed above many differences were found in the behaviour of the different road user groups while they navigated the intersections. While the differences in the behaviour of the different road user groups may cause conflicts among the road users, the design of the intersection can increase the tendency of these conflicts. The intersections had no signage indicating to the road users that there was a junction coming ahead on the road. The intersection infrastructure did not offer any kind of separate lanes for the two-wheelers. The zebra crossing was either absent or had faded or not properly visible. Because the intersection design does not prepare the road users for the emergent behaviours of other user groups, the flexibility brought about by the design of the intersections is problematic.

LIMITATIONS:

The presence of the experimenter while the subjects were performing the experiment may have some effect on the behaviour of the subjects. The data collected while the subjects were alone would be more valid.This study focused on the behaviour of the road users on the signalised intersections only. There was an insufficiency of time at the intersection for participants to express themselves properly. Given more time the participants may have interacted more with the environment. Moreover, all the road user groups were not studied at the same time but under similar conditions. The interpretation of the networks is based on the subjective judgement of the experimenter.

CHAPTER 7: CONCLUSION

This paper studied the behaviour of drivers, two-wheelers and pedestrians while navigating the intersections. The systemic method of the social network analysis was used and found applicable to all the different road user groups. From the analysis, it has been concluded that there is a significant difference in the behaviour of road user groups. Hence the degree of compatibility between drivers, bikers, and pedestrians is not very high. Also, differences were seen in the way they interact with the environment and how they navigate the intersection. Moreover, problems in the intersection design were also noticed. These problems can be reduced with the improvement of the intersection design.for which some suggestions were made. Moreover, each road user group can be trained to think like the other road user group so as to better predict the movements of those groups. This can decrease the potential of road collisions. It is possible to provide integrated plans by taking into account the entire road transport system, including all cars and their occupants, vulnerable road users, pedestrians, roadside infrastructure, the road environment, mobile technology, and in-vehicle systems. This plan should make sure that initiatives in engineering, economics, enforcement, and education are planned and assessed strategically.

FUTURE RESEARCH DIRECTIONS:

In view of the findings and limitations, various future study directions can be thought of. This work can also be analysed using different systemic approaches like Accimap, Cognitive Work Analysis, Situational Awareness Analysis as well as workload assessment techniques like NASA-TLX. This study can also be carried forward in terms of different age groups which will help us understand the type of training each age group requires to better navigate the roads. Gender differences among the road user groups can also be studied. The research for the road user groups can be done on all types of intersections like roundabouts and unsignalised intersections. This research can also help analyse the attentional demands on the user groups while travelling. The time taken by different road user groups can be studied and analysed. With the help of this, the intersection design can be improved to save the time of the user groups. The underlying problems behind the behaviours of the road users can also be understood.

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VERBAL PROTOCOLS

‘I’m just checking the traffic lights ahead’.

‘I’ve just noticed a car pulling up behind me’.

‘I can see that the pedestrian is waiting to cross up ahead’.

‘I am moving to the right lane’.

‘I am approaching the intersection’.

‘I am checking the intersection and determining a route through the intersection’.

‘I am leaving the intersection area’.

‘I am noticing the debris on the road.

‘I am noticing the hole in the road’.

‘I am checking the side mirror’.

‘I am checking the rear-view mirror’.

‘I am revving the engine’

‘I am flashing the indicator’.

‘I am trying to get to the front of the traffic queue’.

‘I am waiting for the green light.

‘I am waiting alongside the divider’.

‘I am noticing the dog in the middle of the road’.

‘I am trying to filter up in the traffic to get to the front queue’.

‘I can see the road marking’.

‘I am sounding the horn’.

‘I am noticing the oncoming traffic.

‘I am noticing the truck in front of the oncoming traffic’.

‘I am noticing the car parked ahead’.

‘I am noticing the road name written straight ahead’.

‘I am noticing the traffic camera’.

‘I am noticing the shops coming ahead’.

‘I am noticing the car waiting adjacent to me’.

‘I am noticing the pedestrian waiting to cross the intersection’.

‘I am now turning right’.

‘I am noticing the arrows ahead’.

‘I am changing lanes’.

‘I am slowing down’.

‘I am speeding up’.

‘I am noticing the highway’.

‘I am changing the gear’

‘I am stopping at a safe distance from the car ahead’.

‘I am overtaking the car.

‘The car ahead of me is turning’.

‘I am navigating the intersection at this speed’.

‘The traffic lights are not visible.’

‘I can see the advertisement hoardings.’