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Thesis title: The influence of the movement of cycle-rickshaws on traffic congestion- A study of heterogeneous traffic conditions in mega-city Dhaka

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Summary

Traffic congestion in Dhaka city is caused mainly because of poor land use and transportation planning, fragmented responsibilities between too many regulatory authorities, violation of traffic rules by vehicle drivers, too many non-registered non-motorised vehicles, inadequate traffic management resources, lack of mass public transportation system and uncontrollable growth of vehicle ownership (Ahmed, 2017). The results from this study show that cycle-rickshaw movement which is a non-motorised vehicle influence traffic congestion. In recent times, Dhaka has become the growth engine of Bangladesh as greater Dhaka generates one-fifth of the country's gross domestic product (GDP) and almost half of its formal employment (Wee, 2018). This attracts massive number of people to migrate to Dhaka city every year because of better socio-economic opportunities. Due to a lack of public transportation, cycle-rickshaws are a popular mode of transportation which for its mismanagement and lack of discipline has given rise to excessive traffic congestion. This study used the theory of heterogeneous traffic flow to derive the sub-variables of the independent variable. It is commonly observed that in developed countries, traffic movement is characterized by a strict lane discipline and single lane motion of vehicles with restricted movement along lanes. This type of movement is called homogenous traffic movement. On the other hand, in developing countries, heterogeneous traffic movement, also known as mixed traffic, on the contrary, is differentiated by the presence of a loose lane discipline and the use of the entire road space without any confinements for manoeuvring (Sharma, Arkatkar and Sarkar, 2011). Furthermore, the presence of wide ranging vehicle types moving in these traffic flow add further to the complexity of the flow (Sharma, Arkatkar and Sarkar, 2011). The area of the study is Dhaka where three prominent and heterogenous roads in Dhaka North, Dhaka South and Dhaka Central were chosen. The objective of the research was to address how non-motorised vehicles like cycle-rickshaws respond to heterogeneous conditions by explaining how cycle-rickshaws movement amongst vehicle types, non-lane discipline movement and traffic-rule violation influence traffic congestion in these three study areas. The type of the research is explanatory and the research strategy is survey. Survey data is further corroborated with interviews and secondary sources for triangulation purpose. Therefore, a mixed methodology is used in the research. Data from survey, interviews and secondary sources revealed that all the three sub-variables influenced traffic congestion in the all the study areas by reducing the average vehicular speed of motorised vehicles. However from statistical correlation tests it was found out the independent variables were only correlated with traffic congestion in Dhaka Central and South but not Dhaka North which with the support of secondary sources concluded that the higher socio-economic characteristics of Dhaka North than the other two areas, causes lower heterogeneousity in traffic flow in Dhaka North than Dhaka Central and South, therefore less levels of traffic congestion in Dhaka North than Dhaka Central and South.

Keywords

Cycle-rickshaw movement. Movement amongst vehicle types. Non-lane discipline movement. Traffic rule violation. Speed Reduction Index. Level of service. Traffic congestion. Spatial based congestion. Temporal-delay based congestion

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Abbreviations

SRI	Speed Reduction Index
LOS	Level of Service
BRTA	Bangladesh Road Transport Authority
DTCA	Dhaka Transport Coordination Authority
RAJUK	Rajdhani Unnayan Kartipakhkha
GDP	Gross Domestic Product
GNP	Gross National Product
UN	United Nations
DTCB	Dhaka transport Coordination Board

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Chapter 1: Introduction

1.1: Background Information

According to a report on urban strategy review, carried out by World Bank in 2018, transport is considered to be the lifeblood of cities from an economical point of view. Transport allows access to jobs, healthcare, education and social services essential for the economic growth of all developed and developing cities and poor transport will only act as an impediment towards that growth. It is reported that the urban sector is responsible for at least a minimum of 50 % of the gross national product (GNP) in most developed and developing cities, where cities invest about or more than 15- 20 % of their annual expenditures in the development of urban transport systems. Urban transportation typically utilizes about 8-16 % of urban household income (Wee, 2018).

In the past twenty years, the annual population growth grate for cities over 50,000 was about 2.5 % with 36 of the cities exceeding a growth rate of more than 6 % annually (Goetz, 2019). However, with the rapid increase of urbanization in most developing cities, urban transportation systems are experiencing an increasing pressure as a by-product of this urbanization.

It is reported in Kuala Lumpur and Sao Paulo, weekday traffic in downtown areas have come down to 10 kilometers per hour or less because of urban traffic congestion. Traffic congestion has increased the cost of operating public transport by 10-16 % in major metropolitan cities like Rio de Janeiro and Sao Paulo. It is also estimated that congestion increases public transport operating costs by 10 percent in Rio de Janeiro (Brazil) and 16 percent in São Paulo. Traffic congestion is also a major reason behind the reduction of growth of measured gross domestic product (GDP) due to delays in freight transportation, difficulties of conducting business in the labour market in mega-cities like Sao Paulo, Mexico city, and Manila (Goetz, 2019). Moreover, urban traffic congestion is responsible for global warming. In industrialized cities, 25 % of gas emissions is contributed by traffic congestion contributing to global warming in industrialized countries. In addition to that an estimated 0.5 million to 1 million people expire each year with pre-condition respiratory diseases due to an exposure to urban air pollution (Goetz, 2019).

There have been numerous possible approaches in order to mitigate or lessen the magnitude of urban traffic congestion over the past. Some examples of possible measures include the improvement of transportation infrastructure, formulation of effective policies to reduce the demand of traffic, and encouraging the use of public transportation from private vehicles to the citizens. All of these have proved to be successful in their own capacity in developed countries however what requires more attention is the management of traffic congestion in developing countries, also known as traffic congestion in heterogeneous or mixed conditions.

Since more than half of the global population is now residing in mega-cities in the developing countries, economical and societal disparities have given rise to the development of ‘cities within cities’. The different levels of land-use patterns of the cities, exist in close

geographical proximity with the land use patterns of its neighbouring cities. The overlapping and co-existence of these land use patterns are reflected in urban travel and traffic patterns in the entire region. Because of this phenomenon, the same road space are used by motorised vehicles like cars, buses, and motorcycles along with non-motorised vehicles such as three-wheelers, bicycles, cycle-rickshaws and animal and human pulled carts (Khan and Maini, 1999). This heterogeneity in vehicle types and lack of lane discipline among vehicles is characterized to be called as heterogeneous traffic conditions commonly seen in developing cities where unlike homogenous traffic conditions like developed cities, traffic movement is not characterized by a strict lane discipline, consisting of similar types of vehicles along a single lane motion with restricted movement along lanes (de Souza *et al.*, 2017).

The presence of motorised and non-motorised vehicles consisting of varied mechanical characteristics and differences in sizes and speed with the absence of properly confined lanes, makes it rather critical for effective urban transport management and service delivery. As many cities allow small operators of informal transport services to operate without hindrance in these heterogeneous traffic conditions without official endorsement, appropriate licenses, permits, or vehicle fitness standards, this results in extremely problematic transport management and traffic flow on urban roads. Furthermore, most drivers employed in this sector are also low-skilled younger men who migrated to urban centres from the rural areas and enter into the informal transport sector without prior traffic knowledge and training (Cervero and Golub, 2007).

Since the past four decades, cities of the developing countries have massively grown in size. The urban cores of the cities have become dense with low-cost housing and crowded streets which have put a negative toll and have made it more costly for planning an efficient public transport service (Cervero and Golub, 2007). Because of a lack of fiscal and institutional capacity by local or national Governments, regulatory public transport services in developing countries have failed to meet the demands of the market. To meet this growing demand, non-regulatory informal transport services have become more and more popular in the last four decades, mostly for on-demand mobility for transit-oriented working class people, as employment opportunities for low-skilled workers and as commute options for areas devoid of public transport services. While these systems provide numerous benefits they also pose threats to the natural and built environment by causing environmental pollution and traffic congestion to name a few (Cervero and Golub, 2007).

In the light of the recent developments of urban areas and its resulting growth of urbanization in the developing cities, city leaders are faced with complex challenges of providing efficient urban infrastructure and initiatives to reduce traffic congestion in urban transportation systems.

1.2: Problem Statement

The current population of Dhaka city is almost 17 million and it is projected to rise to 35 million by the year 2035, making it one of the most densely populated cities in the world (Wee, 2018). With road transport being the dominant component of Dhaka city's transportation system, it is characterized by a chaotic amalgam of private cars, commercial buses, cycle-rickshaws and auto-rickshaws, bicycle, tri-cycles, motorbikes and CNGs etc. Due to the absence of an effective mass transportation system, and the presence of inadequate and unfit commercial bus services, and informal paratransit, cause several externalities with traffic congestion being on the top of the list. Because of this, according to a report on urban strategy review, carried out by World Bank in 2018, the chaotic blend of motorised and non-motorised vehicles that significantly vary in their speeds have reduced the average vehicular speed in Dhaka city to 7 km per hour. It is reported that by the year 2035, due to the increase in travel time and poor transportation management, the average vehicular speed of Dhaka city may reduce down to a speed to 4 km per hour (UN ESCAP, 2018).

Among non-motorised vehicles, a popular mode of transportation meeting the mobility demands of the people of Dhaka city is the cycle-rickshaw. Cycle-rickshaws are a type of informal transport suitable for short distance trips by passengers and carrying of goods. However, according to numerous scholars and experts, because of its role as a slow-moving, informal, non-motorised transport service being driven alongside other regulated motorised vehicles on the roads of Dhaka city, its drawbacks are seen to exceed its benefits.

According to Dhaka metropolitan Police, nearly 1.5 million rickshaw pullers are currently plying in the mega-city and more than 90 per cent of the rickshaw pullers have come to Dhaka city straight from the villages (Begum and Sen, 2005). Due to the lack of a planned and efficient mechanized public transport system, non-motorised transport in Dhaka city provides around 58 % of the total trips in Dhaka city (Olson, 1993). Among these, cycle-rickshaws deliver about 38% of the total trips approximately generating 20.8 million trips every day by the residents of Dhaka city. Sohel (2006) mentioned in his report that cycle-rickshaws occupy 73 % of the total road space in Dhaka city in comparison to other motorised vehicles like private cars, buses and tempos which occupy 19.7 %, 4.4% and 0.4% respectively. Moreover, according to the Dhaka City Corporation, there are 79,554 licensed rickshaws in Dhaka city. However, the actual number of rickshaws are estimated to be 1.1 million (Shafiq, 20171). According to (Sohel, 2006), who also carried out another survey on the knowledge of traffic rules of cycle-rickshaw pullers, found that almost 92% of them did not understand most of the important road signs and markings of Dhaka city. From that survey it was also evaluated that almost 50 percent of the rickshaw pullers did not have any formal educational background. Around 34 percent of the respondent's educational level was within grade one to grade three and among 6 percent of them was found to have only passed the primary level (Sohel, 2006).

As Dhaka city's traffic is heterogeneous in nature, cycle-rickshaws are plying on the same roads as other motorised vehicles of varying mechanical characteristics without any lane demarkations. As cycle-rickshaws are small in terms of size and is operated by human-labour, which significantly differs in speed and size from other motorised fast moving

vehicles, they are considered to be causing a disruption of traffic flow resulting in traffic congestion. Furthermore, due to the cycle-rickshaws lack of license authorization, driving training and knowledge of traffic rules and regulations, they are considered to have unpredictable and irresponsible driving behaviour on roads which interrupts smooth traffic flow resulting in peak and non-peak hour traffic congestion. It is reported that the presence of different vehicles of varying mechanical characteristics due to the differences in vehicular speed and sizes between the motorised and non-motorised vehicle using the same road and due to poor driving habits by the informal transport vehicles namely cycle-rickshaw pullers gives rise to traffic congestion.

It was reported by MCCI & CMILT (2010) that traffic congestion was responsible for the loss of 8.15 million working hours, 40 per cent of which are business hours. The aforesaid money is lost due to 3.2 million business hours wasted in congestion. Again, from another study of Dhaka transport Coordination Board (DTCB), it has been found that against the speed capacity of 40 kilometers per hour (kph), motorized vehicles can run in the city on a speed of average 15 kph. Other externalities due to traffic congestion include the deterioration of quality of life and mental wellbeing as well as physical stress. Furthermore, the impact of traffic congestion on health includes respiratory problems, headache, mental stress, hearing problem, unexpected sweating, tiredness, heart disease, dehydration and many more. In addition to that social wellbeing is impacted as well due to congestion such as reduced social activities, negative influences on choice of transport and location of residence, employment or business, and so on. The drawbacks of traffic congestion are countless for the urban environment and because of this, it makes cycle-rickshaw movement an important component of urban heterogeneous traffic which requires urgent attention in urban transportation research.

1.3: Research objective

This research proposes to develop an analysis of the possible relationship between the movement of cycle-rickshaw movement and traffic congestion. This study aims to provide knowledge that will be beneficial in understanding urban heterogeneous traffic conditions in Dhaka city by explaining how cycle-rickshaw movement influence traffic congestion on mega-city Dhaka.

1.4: Significance:

Since Dhaka city is one of the fastest growing cities in Asia, it needs innovative policies and measures in order to improve its transportation sector. The transportation sector faces challenges which affect the overall city's economic and societal development. As for theoretical relevance, this study fills a unique gap in literature to analyse the influence of cycle-rickshaw movement on heterogeneous traffic conditions in Dhaka city. Even though in Dhaka city, there has been studies done in the past about the role of cycle-rickshaws in urban transportation, however most studies have focused on the role of cycle-rickshaws as a non-

polluting non-motorised vehicle in comparison to other polluting motorised vehicles on the roads of Dhaka city. This study is the first that focuses on the movement of cycle-rickshaws under the complexities of heterogeneous traffic conditions of Dhaka city. Therefore this study goes into depth how cycle-rickshaws interact with other motorised vehicles, disobey lane discipline and violate traffic rules on the roads of Dhaka city. In addition to that, in Dhaka city, the studies done in the past has also mostly focused on the influence of traffic congestion by motorised vehicles and insufficient transportation infrastructure and public transportation. This study is the first that discusses about the influence of traffic congestion by cycle-rickshaw which is a non-motorised vehicle. Furthermore, there has been a gap in international academic literature for heterogeneous traffic conditions in developing countries where non-motorised informal transport plays a huge part in every day phenomenon. Most studies have also been in the context of developed countries where traffic conditions are homogenous in nature. It is hoped that this study will contribute to fulfilling the gap in the management of traffic congestion where traffic conditions are complex consisting of vehicles of varying mechanical characteristics that defines the heterogeneousity of urban traffic roads in the developing world. As for practical relevance, this study is conducted on three significant and heterogeneous roads of Dhaka city. These roads belong to the North, Central and South zones of Dhaka city. The findings of the study can be used to estimate the differences in the levels of congestion on the three zones influenced by the cycle-rickshaw movement and act as recommendations for Dhaka municipalities. Furthermore, the findings of the study can also act as recommendations to the transport sector in regulating the flow of cycle-rickshaws on primary and secondary roads of Dhaka city. Apart from this, the study will provide literature for the further studies of traffic congestion by adopting cycle-rickshaw movement in heterogeneous conditions that has not been studied before in developing cities.
So, this study hopes to provide a reliable and realistic approach to analyse traffic congestion in developing cities as it deals with the complexities of urban traffic heterogenousity. Lastly, In conclusion, it is hoped that this research can be beneficial for city leaders, experts, consultants and professionals in private and public sector in achieving future advancements in sustainable transportation systems in Dhaka city.

1.5: Research Questions

Main Research question: How does the movement of cycle-rickshaws influence traffic congestion in Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Asad Gate to Mohammadpur Bus stop (Dhaka Central) and Shahbag Square to Science laboratory (Dhaka South)?

- Sub-variables of cycle-rickshaw movement (independent variable) : movement amongst vehicle-types, non-lane discipline movement and traffic-rule violation

- Sub-variables of traffic congestion (dependent variable) : temporal-delay based congestion and spatial based congestion

Sub-question 1: What is the current state/condition of traffic congestion in Dhaka North, Dhaka Central and Dhaka South?

Sub- question 2 : How does the movement amongst vehicle types by cycle rickshaws influence traffic congestion in Dhaka North, Dhaka Central and Dhaka South?

Sub-question 3: How does non-lane discipline movement by cycle-rickshaws influence traffic congestion in Dhaka North, Dhaka Central and Dhaka South?

Sub-question 4: How does traffic rule violation by cycle-rickshaw movement influence traffic congestion in Dhaka North, Dhaka Central and Dhaka South?

Chapter 2: Literature review/theory

2.1: Introduction

This chapter uses concepts and theories to explain the background of the problem discussed in chapter 1. The study attempts to understand the accountability of cycle rickshaw movement on traffic congestion based on international academic relevance. State of the art theories and concepts discussed in this chapter were rooted in the main variables of the research question. The chapter introduces the first independent variable which is the movement of cycle-rickshaws and the theories associated with it. The sub-variables and possible indicators for the independent variable were derived from the theory of heterogeneous traffic flow and traffic management theory. Additionally, the chapter explains the dependent variable which is traffic congestion and its sub-variables by using the spatio-temporal congestion theory. Finally, the chapter shows the link between cycle-rickshaw movement and traffic congestion and explains the relationship between the independent and dependent variable. Lastly, the chapter provides a conceptual framework of the research formulated based on theories, concepts and empirical studies.

2.2: Urbanization and Urban Transportation

Rapid urbanization around the world is the major reason behind the numerous quantities of journeys in urban areas. In the industrialized world, due to the population influx of urbanization which results in increasing motorization, it is of utmost importance that urban transportation system must work towards meeting the needs of this ever-increasing population movement. Failure in meeting this growing demand, has resulted in transportation service bottlenecks that gives rise to urban traffic congestion (Goetz, 2019). Since congestion is a highly complex problem, there is often no clear and single method to tackle its emergence. However, by increasing the public transportation supply, increasing infrastructure capacity, improving infrastructure conditions and by effective usage of traffic policies and regulations, urban transportation system has been tackling the emergence and consequences of traffic congestion since ages in the most heavily inhabited and industrialized cities of the world (UN ESCAP, 2018).

2.3: Variable (Dependant): Traffic Congestion

There has been various definitions of traffic congestion developed and adopted by different researchers and practitioners in the past. The adoption of these definitions depend on understanding each context at which traffic congestion is taking place and the kind of parameters the researcher is willing to measure. For example, traffic engineers state that congestion is a phenomenon that arises when the input volume exceeds the output capacity of the facility (Stoper, 2003).

Traffic congestion simply means that the road capacity is not enough to cope with vehicles trying to use it (Kumarage, 2004).

According to (Kumarage, 2004) traffic congestion occurs when the infrastructure capacity does not respond to the demand of vehicles over it. Hence, according to the author traffic congestion is the imbalance between demand and supply sides of transport infrastructure. But Downs (2004) defined that congestion occurs when the vehicle moves at a speed lower than the infrastructure is designed to maintain, resulting in delay. Traffic congestion also be defined as a state in the traffic flow pattern which represents the condition at which demand exceeds capacity or the speed is below acceptable value (Yu, et. al., 2010). On the other hand, the term congestion can be also defined as the situation which occurs if the introduction of a vehicle into a traffic flow increases the travel times of the other vehicles by more than x percent" (Bull, 2003, p.25). Further to the above; many more researches have been conducted by different researchers and professionals to develop measuring parameters and models to measure traffic congestion (Maitra et. al., 1999).

Traffic congestion can also be classified into two categories depending on its occurrence. These are recurring congestion and non-recurring congestion. Congestion that results due to predictable events are considered to be recurring congestion and congestion that arises due to accidents and unprecedented events are termed as non-recurring congestion (Skabardonis et. al., 2003). In this paper congestion is defined as a recurring incident. Traffic congestion impacts the sustainability of cities. However, according to Kumarage (2004) traffic congestion impacts the economic development of the city by causing delays in business hours, it impacts life satisfaction among the city inhabitants by causing road traffic accidents, deteriorates the environment by polluting the air quality and reduces social wellbeing giving rise to frustration and mental stress among the vehicle drivers.

Generally two approaches are widely used for measuring traffic congestion: an operational approach that is concerned with observable features of road performance (speed, flow, density, queue length and duration), and the other is an economic approach that typically focuses on translating physical measures into monetary values for performing a cost-benefit analysis (Rao, 2012).The operational approach seems to be the overwhelmingly dominant approach by most researches. Because of this reason and the limitation of time and resources allocated for conducting this research, the operational approach seems to be the appropriate approach to measure traffic congestion for this study.

In general, to measure traffic congestion according to the operational approach, indicators used can be broken down into two broad groups: temporal based indicators are basically point related measures such as travel time and delay, speed based indicators, vehicle count and flow or spatial based indicators such as density, queue length, congested lane kilometres, level of service, etc (Rao, 2012).

Therefore, this study categories traffic congestion into temporal-delay based congestion and spatial based congestion. The study tries to measure congestion from perspectives, from the temporal perspective where the measure of congestion is estimated by the delay in productive hours and also from the spatial perspective, where the measure of congestion is estimated by the spatial perspective where the measure of congestion is estimated by the quality of the road traffic. Temporal and spatial based congestion are further discussed below.

2.3.1. Sub-variable (Dependant): Temporal-delay based Congestion:

According to US Department of Transportation, Federal Highway Administration, measuring congestion by times of the day and day of week has been a popular practise since ages. New approaches to measure congestion based on temporal analysis are weekday "peak period" travel time (Mohan Rao and Ramachandra Rao, 2012). In large metropolitan areas, congestion lasts for a long time example, several hours each weekday morning and evening. In conclusion, congestion has spread into more hours of the day which forces commuters to plan and leave much earlier than they are supposed to leave. That is why peak period travel tome is critical in measuring temporal based congestion (Mohan Rao and Ramachandra Rao, 2012).
According to (Lomax et al., 1997), some examples of temporal based indicators to evaluate traffic congestion are time loss or delay, accessibility, travel time and relative delay. However, the indicators do not categorize congestion levels in different road sections. The authors in their study mentioned that traffic volumes in different sections of an urban arterial may very significantly from each other.

Most authors have mentioned that traffic congestion is measured with the ratio of travel time in peak period with the travel time in off-peak period. According to (Mohan and Ramachandra, 2012), the intensity of traffic congestion can be measured by comparing the ratio of average vehicular speed of during peak period and off-peak periods. Speed is the main factor that influence travel time and delay (Lomax ,1997). According to (Saw et al., 2016) severe levels of congestion exist when peak period travel time by the vehicle is way more than off-peak period travel time. Congestion measurement approaches depend on the researcher and what he or she is trying to address. However, travel time indicators that deals with speed helps decision makers to take concrete actions in the field of urban transportation (Dzintars, 2017).

2.3.2. Sub-variable (Dependant): Spatial based Congestion:

According to US Department of Transportation, Federal Highway Administration, congestion spreads not only in time but in space as well (Rao, 2012). Queues from physical bottlenecks and major traffic-influencing events (like traffic incidents) can extend for many miles. Therefore congestion should measure portion of roadway or lanes that are occupied during peak hours. Spatial based congestion measures should aim to measure congestion over

facilities or corridors (Mohan Rao and Ramachandra Rao, 2012). Spatial based congestion can also be estimated by measuring level of service. The level of service (LOS) has been traditionally a popular measure of traffic congestion.

Apart from measuring traffic congestion quantitatively, it can also be measured qualitatively. Level of service (LOS) can be used to identify the quality of traffic flow comprising vehicles. It can be used to analyze the quality of traffic flow in intersections and roadways by assigning levels of quality of traffic flow based on performance measuring indicators like average vehicle compactness, speed, density, volume to capacity ratio (Aftabuzzaman, 2007). Levels of service can be categorized A to F ranging from least congested (A) to most congested (F).

Fig 1: Level of service for different speed limits

Level of service	Average vehicle speed	Quality of road
A	>40 km/h	Free flow
B	>32-40 km/h	Stable vehicle flow
C	>24-32 km/h	Stable vehicle flow
D	>16-24 km/h	Less stable vehicle flow
E	>8-16 km/h	Unstable vehicle flow
F	≤8 km/h	Forced vehicle flow

Source: (Deshpande et al., 2010)

Many authors stated that level of service is a useful indicator as it is non-technical and can be used by most number of people. However, (Aftabuzzaman, 2007) stated a criticism of level of service that the quality assigned to the traffic flow of a given congested area is limited to the traffic flow of that area only, which gets challenging when the traffic congestion is at the edge. Moreover, Moran (2011) mentioned that level of service does not go beyond in analyzing the congestion within a specific category. This study uses level of service as a spatial based congestion by categorizing them into quality of traffic flow from A to F based on the peak-period and off-peak period vehicular speed as discussed below.

2.4: General information- Cycle-rickshaw

A rickshaw originated in 1879 is a two or three-wheeled cart used to carry passengers or goods, usually pulled by one man carrying one or two passengers. During the 19th century pulled rickshaws were either used as a means of transportation or as a popular source of employment for male laborers in Asian cities. The popularity of human pulled rickshaw started to decline as motorized vehicles like cars, trains and other forms of transportation

became widely available to carry goods or passengers. Over time, the original pulled rickshaws have been replaced with the invention of more evolved and efficient design of rickshaws like cycle-rickshaws, auto rickshaws, and electric rickshaws. However, it still exists in some parts of the world for tourism purposes.

Cycle-rickshaws are a non-motorized, tri-cycled vehicle usually human-powered operated by pedaling of the rickshaw puller and are used for making short-distance trips on a for-hire basis.

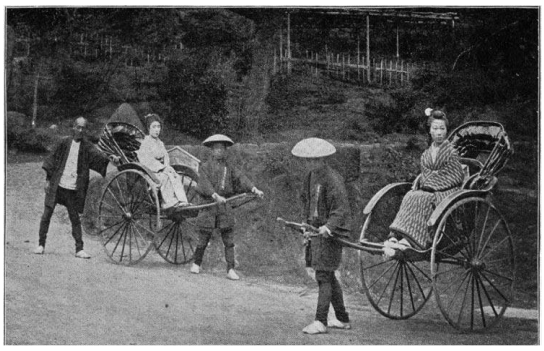


Fig 2: Japanese pulled rickshaw(Revell,1897)

Fig 3:Bangladeshi cycle rickshaw(Rashid,2015)

2.5. Movement of cycle-rickshaws (Independent variable):

Cycle-rickshaws are considered to be an example of informal transport in Dhaka city. 'Informal transport', also known as ' para-transit,' 'low-cost transport', and 'intermediate technologies' are small-scale, privately operated services found in all cities of the world however commonly seen in developing cities (Cervero and Golub, 2007). Unlike taxi services for-hire basis, the drawbacks of informal transport service is that the operators of informal transports often lack to some degree official credentials, necessary permits or registration for entering into a regulated marketplace. In many cases, operators fail to meet certification requirements, vehicle fitness standards and driving licenses (Cervero and Golub, 2007).

There have been numerous arguments both positive and negative about the operation of informal transport services like cycle-rickshaws on urban roads in developing cities. According to a report carried out in 2002 by World Bank, informal transport services like cycle-rickshaws, minibuses, vans, taxis, station wagons, three-wheelers and motorcycles are a major source of employment for the low-skilled migrants that come to the cities from rural areas in developing countries. According to (Shimazaki and Rahman, 1995), there are about 380,000 people and a further 80,000 people employed as Rickshaw pullers and other ancillary services related to rickshaw pulling respectively. However, according to World Bank (2002) officials, the negative consequences of informal transport outweighs the benefits as these vehicles are believed to contribute to traffic congestion in developing cities. According to (Cervero and Golub, 2007) the erratic scheduling and aggressive travel behaviour of cycle-rickshaws competing to pick up passengers during peak periods is a major factor of urban road traffic congestion. The authors further went on to mention that the poor driving habits of informal transport drivers is because of the fact that most of them lack

proper trainings and legitimate credentials. Moreover, informal transport services have also been held accountable for a high number of accidents in developing countries. Similarly, Shimazaki and Rahman (1995) in respect to the above statement mentioned that 54 percent of all urban accidents in Ankara (Turkey) involved informal transport services. In Dhaka city, it was reported that cycle-rickshaws in comparison to other modes of transport contributed to 2.3 % of traffic accidents compared to other motorized vehicles. In many instances, road traffic accidents are not reported due to cycle-rickshaws not being registered. Other than that, researchers have claimed that due to the long and strenuous working hours of rickshaw pullers, they contribute to congestion and accidents. Other causes of traffic congestion by rickshaw movement are the plying of rickshaws on the same roads as other motorised vehicles. This further reduces overall vehicular speed of the traffic and decreases road capacity (Shimazaki and Rahman, 1995). This was proven by a study carried out by Shimazaki and Rahman in 1995 that a cycle-rickshaw is about 20 times more inefficient than other motorised vehicles such as bus and minibus in terms of road capacity.

2.5.1. Homogenous vs heterogeneous Theory of traffic flow:

There have been many theoretical perspectives that explain driver's behaviour of non-motorised transport but most of them are based on homogenous conditions. It is commonly observed that in developed countries, traffic movement is characterized by a strict lane discipline and single lane motion of vehicles with restricted movement along lanes. This type of movement is called homogenous traffic movement. On the other hand, in developing countries, heterogeneous traffic movement, also known as mixed traffic, on the contrary, is differentiated by the presence of a loose lane discipline and the use of the entire road space without any confinements for manoeuvring (Sharma, Arkatkar and Sarkar, 2011). Furthermore, the presence of wide ranging vehicle types moving in these traffic flow add further to the complexity of the flow (Sharma, Arkatkar and Sarkar, 2011).

According to Asaithambi et al., current and widely researched driver behavior models in homogenous conditions do not explicitly consider the wider range of situations that drivers in mixed traffic face. The behaviour of such traffic is ensured by the existence of traffic flow variables that vary over space and time and therefore it is essential for understanding the nature of a heterogeneous traffic moving on the road to identify these variables (Sharma, Arkatkar et al., 2011). According to (Sharma, Arkatkar et al., 2011) mixed or heterogeneous traffic flow can also be defined as a traffic stream containing various vehicles-either motorised or non-motorised .The authors also defined heterogeneous traffic flow as the result of the interaction between components of land use, road infrastructure, and vehicles of both motorised and non-motorised types. Slinn et al. (2005) in another study defined heterogeneous flow as, 'the movement of pedestrians, cyclists and motorised vehicles along the route'. Furthermore, it was also reported that in heterogeneous traffic streams in the presence of a mixture of vehicle types and loose lane regulations, driver behaviours in cities

in developing countries is complex and rule-violating (Sarlas, Papathanasopoulou et al., 2013).

The theory of heterogeneous traffic flow is a significant theory for this research as traffic flow is heterogeneous in nature in many parts of Dhaka city with informal transportation vehicles, especially cycle-rickshaws being a significant component in it. From the above discussions, the independent variable 'movement of cycle rickshaws' of this study was categorized into three sub-variables based on the theory of heterogeneous traffic flow and relevant academic literature of driver behaviour in heterogeneous traffic flow. The sub-variables are 'movement amongst vehicle types', 'non-lane discipline movement' and 'traffic-rule violation' respectively. A more in depth discussion of the sub-variables are presented below.

2.5.2. Explaining the movement of cycle-rickshaws amongst vehicle types (Sub-variable):

As heterogenous traffic flow is characterized by vehicle types and non-lane discipline, the first sub-variable chosen for this study is the movement of cycle-rickshaws amongst vehicle types. According to (Khan and Maini, 1999) the blend of fast-moving and slow-moving vehicles characterizes heterogeneous traffic flow. Examples of fast-moving vehicles include cars, buses, trucks, auto-rickshaws, scooters, motorcycles, and mopeds and some examples of slow-moving vehicles include bicycles, human-powered or cycle-rickshaws, and animal drawn carts. All these vehicles vary in both size, manoeuvrability, control, flexibility and static and dynamic characteristics. Heterogeneous traffic flow usually classifies vehicle types into two groups, speeds and sizes. Since all these vehicles of different speeds and sizes, both motorised and non-motorised vehicles tend to travel in the same right-of-way they tend to have an impact on one another (Khan an Maini, 1999). It is also reported that, the interaction of varied forms of motorized and non-motorised transport is a major cause of congested urban roads which is often frowned upon by local authorities and urban planners. Many experts claim that these vehicles should be separated as much as possible because of their types, characteristics, speeds and lane width requirements'' (Khan and Maini, 1999).

Many authors over the past have tried to develop heterogeneous traffic flow modelling to study driver behaviour. Of these, the most common characteristics in a mixed or heterogeneous traffic flow was that a single vehicle tend to follow multiple leader vehicles of different speeds and sizes. The authors also mentioned that there are noteworthy differences between each leader following manoeuvre by cycle-rickshaws. Therefore for modelling a realistic and reliable heterogeneous traffic flow simulations, it is important to consider different following manoeuvres of vehicles following leader vehicle in its vicinity (Budhkar and Maurya, 2017).

According to (Sarlas, Papathanasopoulou, et al., 2013), in a heterogeneous traffic flow the difference in speeds between the leader and the following vehicle is large and it is often seen

that following of the leader vehicles increase due to the complexity of the traffic even when there should be limited opportunities to follow. Khan and Maini (1999) mentioned that as rickshaws are being operated by human labour, it tends to have significantly lower speeds than its other neighbouring vehicles on the same road which significantly impacts its neighbouring vehicles. The authors also conducted a study on a heterogeneous road to further establish their point where they found that vehicle speed variations range from a maximum 14 m/s to minimum 9 m/s. The authors mentioned that the speed variations also meant that different vehicles have different manoeuvring capabilities, hence their acceleration capabilities were different. Khan and Maini (1999) also mentioned that the ongoing traffic speed at any section of a roadway affects the cumulative quality of the traffic at that time. Whereas excessive speeds could be a major factor leading to road traffic accidents and traffic flow disruptions, very low speeds in the urban environment is also indicative of traffic congestion. Since congestion is often defined as a function of a reduction in speeds, which is the direct cause of loss of time, the presence of cycle-rickshaw pullers can be considered to a key issue in urban traffic congestion in heterogeneous conditions (Rao, 2016).

According to (Sarlas, Papathanasopoulou,et al., 2013), in heterogeneous traffic flow, the differences in sizes of vehicles also have an impact on the overall traffic flow. The authors mentioned that small sized vehicles such as motor cycles often occupy available lateral and longitudinal gaps on the road space or utilize gaps between large vehicles in traffic stream. According to (Munigety and Mathew, 2016), the size and weight of a vehicle also influence driver's turning capabilities. The authors mentioned that the larger the vehicle, more space it covers on the road therefore less flexibility in manoeuvring. For example, a heavy vehicle like truck offers less flexibility to its driver while manoeuvring on a traffic stream. On the other hand, a small-sized vehicle such as a motorbike or rickshaw offers more flexibility to its driver in moving within vehicles along the traffic stream.

Therefore, the presence of wide ranging vehicle types of both speeds and sizes affect the surrounding vehicles and their drivers, resulting in either an increase or drop in the roadway capacity. This vehicle-type variability is apparent in traffic conditions prevailing in developing countries such as Bangladesh, China, Indonesia, and India (Munigety and Mathew, 2016).

2.5.3. Explaining the movement of cycle-rickshaw with non-lane discipline movement (sub-variable)

The second sub-variable chosen for the independent variable is non-lane discipline movement by cycle-rickshaws as heterogeneous traffic in developing cities is characterized by loose lane discipline conducted by vehicle types. There has been many traffic simulation models formulated for lane-based conditions however, simulation of mixed traffic flow in weak lane based, heterogeneous conditions poses additional challenges. Munigety and Mathew (2016) have identified that due to weak lane discipline, drivers manoeuvring skills exhibit some peculiar patterns such as swerving and lane-splitting. The authors also mentioned that drivers

also maintain shorter headways while manoeuvring in non-lane based traffic streams. According to (Munigety and Mathew, 2016) drivers in mixed traffic tend to swerve or weave away from its lane. Since drivers in mixed take advantage of not maintaining minimum safety gap between the vehicles, they tend to tailgate their leader vehicle by aligning to one of its lateral edges. When the subject vehicle sees the possibility to collide with the leader vehicle, it swerves off from its current position away from its lane in order to avoid collision with the leader vehicle. Khan and Maini (1999) suggested that rickshaw pullers often makes an immediate or abrupt decision to change direction or swerve even if the traffic is flowing in one particular motion. This change in manoeuvrability of rickshaw pullers in heterogeneous traffic flow creates disruption for not only the vehicles that are surrounding it but also to the ones that are behind it often leading to chaos and disorder on urban traffic systems (Khan and Maini 1999).

Lane-splitting is another behaviour that drivers in mixed traffic follow. Lane splitting, white-lining, or stripe-riding in many cities of the world is moving between lanes of stationary or slow moving traffic moving in the same direction. Lane-splitting allows the drivers to save time, by by-passing traffic congestion (Munigety and Mathew, 2016). According to (Parsuvanathan, 2015) small vehicles in developing countries assume any free space to be virtual lanes and try to move through it to avoid being stopped at traffic for long hours. According to (Agarwal and Lämmel, 2015) in congested roads, smaller vehicles like motorbikes, bikes and three-wheelers do not stop at the end of queues. Instead, they move continuously across the gaps between stationary congested vehicles. This is easily done by them because of their flexibility in manoeuvring and their small size. Madhu, Sivanandan and Srinivasan (2020) mentioned that in mixed traffic streams, where the vehicles are restricted to perform free manoeuvres during congestion, two and three-wheelers use their opportunity of flexible manoeuvring and size to move through the gaps available between the vehicles which gives them the benefit of operating under maximum capacity to reach their destination. This behaviour leads to overall chaotic vehicular movement patterns of the traffic stream and can cause adverse traffic congestion and accidents. Khan and Maini (1999) explained the behaviour of cycle-rickshaw movement on heterogeneous urban traffic stream where they mentioned that rickshaw pullers manoeuvring capabilities could create disruption for other fast moving or large scale motorised vehicles. As rickshaw-pullers manoeuvre in order to follow the target direction which is the direction in which they intend to move on to reach their target destination, he will often try to achieve the easiest path to reach the destination in least travel time even when there is adverse traffic congestion. Since quicker way to the destination means more revenue, he will try to manoeuvre between available gaps of stationary vehicles using all scopes causing a chaos and disorder in overall vehicular traffic movement (Khan and Maini, 1999).

2.5.4. Explaining the movement of cycle-rickshaws with traffic rules violation (Sub-variable 3) :

In cities, where the number of vehicles continuously increase faster than the available traffic infrastructure to support them, congestion is a difficult issue to deal with (de Souza *et al.*, 2017) . Traffic management systems are composed of a set of application and management tools to improve the overall traffic efficiency and safety of the transportation systems. Furthermore, to overcome such issue, traffic management system gathers information from heterogeneous sources, exploits such information to identify hazards that may potentially degrade the traffic efficiency, and then provides services to control them. One component of traffic management system is to enforce and implement effective traffic laws and regulations on urban traffic roads (de Souza *et al.*, 2017) . Traffic violation law covers any number of unlawful activities involving a motor vehicle (de Souza *et al.*, 2017) These laws deal with moving violations like drunk driving, speeding, ignoring traffic signs and signals, wrong-way driving , driving without license or with an unauthorized license or violations related to the fitness of the vehicle.

Traffic signs are the most commonly used devices for controlling traffic. These sign sconvey messages in terms of words and/or symbols, and are placed to regulate, warn or guide roadusers (Pignataro, 1973). They are essential when different regulations apply at specific places and times or where hazards are not self-evident (Pignataro, 1973). Traffic signs are most effective when they comply with the following requirements: fulfill a need, command attention, convey a clear and simple message, command respect of the road users and give adequate time for proper response (Pline,1992). Road users depend on signing for information and guidance, and road authorities depend on signing for traffic control and regulation, and for road safety.

The three main functions of traffic signs are to regulate, warn and inform. Each group of signs have a uniform shape to help drivers recognise them quickly. They tell drivers what they must not do (prohibitory), or what they must do (mandatory). These warn drivers of some danger or difficulty on the road ahead. Most of these signs give drivers information to enable them to find their way to their destination. Apart from traffic signs, another important group of signs are Road Markings. These can regulate, warn and inform, and some help clarify or emphasise the message given by other signs (Bangladesh Road Sign Manual).

However, in developing cities, knowledge about traffic signals and symbols have been reported to be low by road users especially among rural migrants who come to urban areas to drive vehicles. According to (Sun, Yang, et al., 2013), a study on travel behaviour of rural migrants in Shandong Province in China revealed that most migrants have weak awareness of traffic safety when using urban transport roads. Since most migrants have migrated to urban centres from rural areas where there is limited education and poor road conditions, they seem to be unaware of traffic safety especially during crossing roads, riding mopeds and taking buses. Further, it also suggests that migrants have not developed good practises of obeying traffic rules which results in negative consequences often resulting to road traffic accidents. In addition to that, some travel behaviour such as driving without proper license, drunk and

stress driving are very common for migrant workers. These practices influence problems in the smooth traffic flow of urban traffic resulting to negative consequences if not properly managed (Sohel, 2006). In order to conduct traffic safety education for migrant workers efficiently, a questionnaire survey to investigate their knowledge of traffic safety was held in Xinghua City, Jiangsu Province. The survey revealed that about 56% of migrant workers have a low level of traffic safety education and a lack of traffic safety knowledge (Sun and Yang, 2013). Similarly, In Dhaka city, cycle-rickshaw pullers were assessed about their actual understanding on road signs and symbols, they were asked if they recognised four signs (no parking, no-entry, pedestrian crossing and school ahead). From the results it was evaluated that more than 90 percent of the rickshaw pullers did not understand most of the major road signs and symbols in Dhaka city and it was concluded from the survey that 92% of them did not have traffic knowledge and education (Sohel, 2006). In Dhaka city, it is considered that due to the lack of education, traffic knowledge and prior training, migrant cycle-rickshaw pullers tend to violate traffic laws. Their lack of neglecting traffic signs and signals often lead them to violate traffic laws while they are in motion (de Souza *et al.*, 2017).

Moreover, it was found that traffic law violations by vehicle drivers tend to be higher during the evening than the morning as vehicle drivers take advantage of violating laws in the darkness during peak periods (Ibadan, 2020).

Additionally, negative attitude of drivers such a overtaking, wrong-way driving, disobeying traffic signals and illegal dropping and picking of passengers have been identified as traffic law violations (Remi et al., 2009).

According to (Al-Madani and Al-Janahi, 2002) as demand approaches the capacity of a road, extreme traffic congestion sets in. When vehicles are fully stopped for periods of time, the drivers are suffer through extreme levels of stress and suffer financial burden because of loss of productive hours. To bypass this physical and emotional stress of traffic jams, impatient drivers tend to look for means of boycotting the traffic congestion to an extent of violating the lay down traffic laws. Moreover, the authors mentioned that traffic violations have been observed to be a rampant offence for commercial drivers apart from drivers of privately owned vehicles. Commercial vehicles seem to break traffic regulations when the traffic rate is high and this reduce the unproductive time wastage on the road which otherwise would have been utilized to pick up more passengers to maximize profit. Prolonged traffic congestion seems to hinder the targeted amount of the commercial drivers, this at time makes the drivers to be involved in traffic violation such as over speeding, passing the wrong traffic lane and ignoring other traffic signs and signals (Al-Madani and Al-Janahi, 2002).

2.6. Conceptual Framework:

The diagram represents the relationship between the independent and the dependent variable. The independent variable is the movement of cycle-rickshaws and the dependent variable is traffic congestion. There are three sub-variables for the independent variables namely movement amongst vehicle types, non-lane discipline movement and traffic-rule violation and two sub-variables for the dependent variable namely temporal delay based congestion and spatial-based congestion.

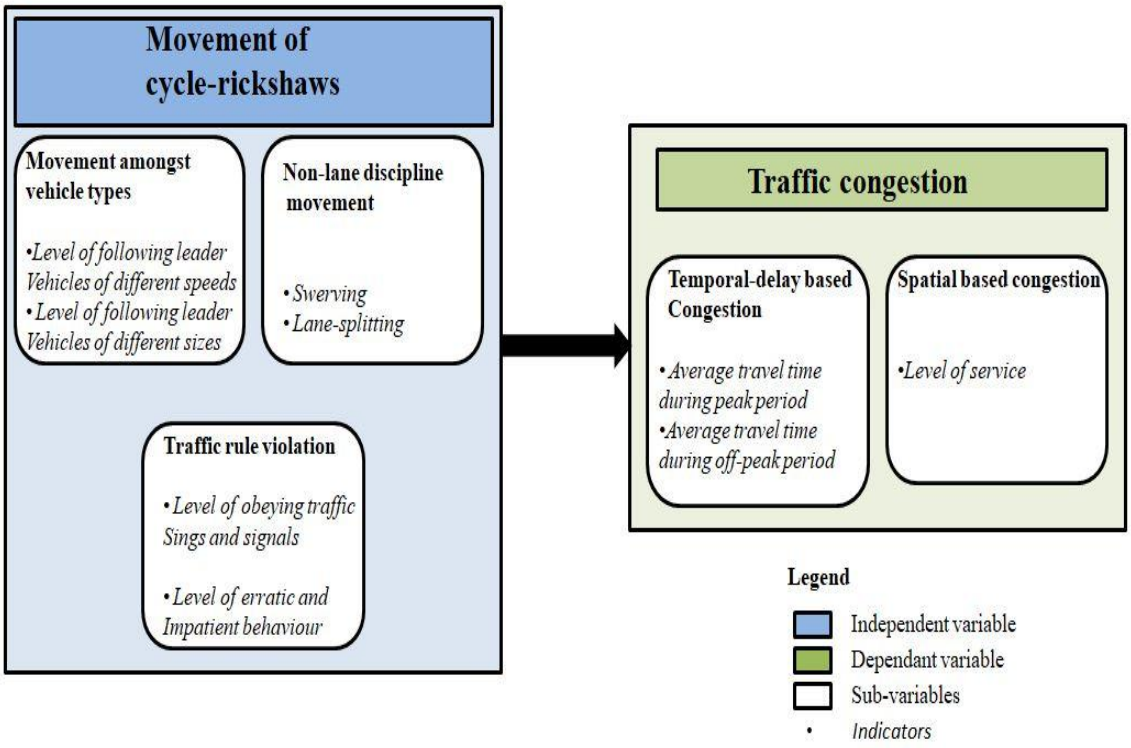


Fig 4: Conceptual Framework

Chapter-3: Research Design, methods and

This chapter begins with the research design that was adopted for the study highlighting the research strategy, data collection methods, description of sample size selection of study area and various techniques used to analyse the data collected are presented. Further, the validity and reliability of the research strategy and methodology are explained as well. Additionally, based on the conceptual framework as reviewed by various concepts/theories, the variables, sub-variables and indicators are defined and finally operationalised as shown in the operationalisation table. Finally, the challenges and limitations of the research design are presented as well.

3.1. Description of the research design and methods:

3.1.1. Research Type and Strategy :

The research type is explanatory as the research aims to find out the causal relationship between the movement of cycle-rickshaws and traffic congestion in mega-city Dhaka. It aims to find out how the movement of cycle-rickshaws (independent variable) is influencing the traffic congestion (dependent variable) on Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Shahbag Square to Science laboratory (Dhaka Central), and Asad Gate to Mohammadpur Bus stop (Dhaka South) in mega-city Dhaka.

The study uses the survey strategy which involves a systematic collection of quantitative information from a large pool of respondents and an in depth collection of qualitative information from a group of interview respondents (Thiel, 2014). The survey strategy is used for gathering data from a large pool of information which can be converted into quantified forms for analysis. Even though triangulation is not required for conducting surveys however closed-ended interviews and secondary sources were used to corroborate the results.

To conduct the research, firstly, primary data from vehicle drivers rickshaw passengers, traffic police and pedestrians were collected for the independent variable. The dependent variable data is collected from both primary and secondary sources namely survey respondents and google maps.

3.2. Research Methods:

3.2.1. Data Collection Methods :

The study adapted mixed methods including quantitative and qualitative data by focusing on collecting primary data from surveys (questionnaire) and interviews and by also applying triangulation with secondary data including academic literature, reports and google maps.
Mixed method was adopted for this study as the researcher was interested in analysing the level of traffic congestion experienced by a large sample size, therefore quantitative data was

collected through surveys and the researchers was also interested in how or in what ways is congestion influenced by cycle-rickshaw movement hence, qualitative data from structured interviews accommodated that. Not to mention, triangulation of data with secondary sources provided validity and reliability of the findings where both quantitative and qualitative data was collected.

For quantitative data, motorised vehicle drivers who regularly commute along the roads of Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Shahbag Square to Science laboratory (Dhaka Central), and Asad Gate to Mohammadpur Bus stop (Dhaka South) were surveyed. The respondents chosen for the survey also commuted regularly and during both peak and off-peariods of morning and evening times. The interview respondents were also selected who regularly commute or patrol on the three study areas. The selection of these key informants for interviews are explained more in detail in section 4.4.3. The final set of interview respondents included traffic police, cycle-rickshaw passengers, vehicle drivers and pedestrians. All the survey and interview questions were formulated based on the indicators selected on each variable and the data required to answer the research questions.

3.2.2: Sampling size and selection

The total population of registered vehicles in Dhaka city is collected to calculate the sample size of the population. This sample size is calculated because it is not possible to provide questionnaires to the entire population and quantify information from it (Thiel, 2014). The sample size is calculated from a computer based equation Therefore it is necessary to draw a sample that best represent the entire unit of study. A margin of error of 5% and confidence interval level of 95% is used to calculate the sample size.

The sample size is determined using formula n= (z 2 *p*q)/d2 (Source: Survey Monkey, 2018)

Total population of registered vehicles in Dhaka city- 166,840 (Bangladesh Bureau of Statistics, 2018)
Sample size of respondents- 400 (confidence interval 95 % and margin of error 5 %)

Random sampling is performed as a sampling method to identify the respondents (vehicle drivers) to carry out our survey. Random sampling is a probability sampling technique which selects units of survey from an unknown population on the basis of chance.

3.3. Validity and Reliability:

Reliability of the research was achieved by creating an adequate sample size in order to improve levels of consistency of the study's results. The variables were effectively operationalized into quantifiable measures to analyse the data collected which increases

internal validity. To improve the validity of the survey research strategy, an average of 3-5 pilot interviews was conducted with the vehicle drivers. This allowed me to understand if the terminologies used in the final questionnaire is well understood and received by the respondents. As the respondent group belongs to the group with the lowest literacy level of Bangladesh, the pilot interviews allowed me to standardize the language of the final questionnaire into simplified and contextual manner before conducting the final survey. The next step was to redesign or modify the questionnaire according to the observations collected during the interviews and further conduct a survey among 3-5 cycle-rickshaw pullers to fill out the modified questionnaire. This showed me if the items in the questionnaire are well understood by the respondents. All these steps are followed to minimize the risk of non-responsive answer errors in the questionnaire before the final survey is being conducted among the sample population. Moreover, the questionnaire was translated into Bangla language (national language of Bangladesh).

Reliability relates to how accurate and consistent the variables of a study are measured (Thiel, 2014). The variables of a study would be measured by indicators that are clear and precise as shown in the operationaization table (Thiel, 2014). Moreover the indicators used were also used in similar researches related to non-motorised vehicle in heterogeneous traffic conditions. The measurable items should be such that their use in similar studies should provide similar findings. In addition to that, theories, concepts and methodologies included in the study were formulated from previous academic literature to further improve reliability and external validity of the research.

3.4. Data Analysis Techniques:

Quantitative primary data collected by the survey would be transferred to quantifiable measures and would be analysed through SPSS (The statistical package for social sciences) software – a tool for statistical analysis. The research topic required measuring the influence of movement of migrant cycle-rickshaw pullers (independent variables) contributing to traffic congestion (dependent variable). Therefore the study aimed to predict the value of the dependent variable based on the values of the independent variables. Descriptive statistics was used to analyse the data. As a descriptive statistical analysis technique correlation technique was used to measure how strongly two variables are interrelated. Qualitative data from interviews are are coded and categorised into thematic ideas and trends according to the number of times it is mentioned by interview respondents. Therefore, frequency distribution tables are created according to the themes collected under each indicator and further used to corroborate the findings of the survey data.

3.5: Operationalization: Variables and indicators

3.5.1. Definition of Theories/ concepts

Heterogeneous traffic flow- It is defined as the traffic flow that consists both fast-moving and slow-moving vehicles or motorised and non-motorised vehicles (Edie, 1965).

Traffic management theory- Traffic rule violation is derived from traffic management theory. Traffic rule violation covers any number of unlawful activities involving a motor while the vehicle is still in motion (de Souza *et al.*, 2017)

Spatio-temporal congestion-

Temporal based congestion: Time lost/delay or hours of extra travel time caused due to congestion is defined by temporal based congestion

Spatial based congestion: Portion of roadway miles/kms that are occupied or congested during peak periods is lefined by spatial congestion

3.5.2 . Definitions of variables and sub-variables

3.5.3. Movement of cycle-rickshaws (Independent variable 1)

Sub-variable-1: Movement in the presence of different vehicle types

In heterogenous traffic conditions, cycle-rickshaws tend to follow leader vehicle of different speeds and sizes to pass through traffic. Some of the types of leader following behaviour by drivers in heterogenous traffic is tailgating, travelling abreast and overtaking which are defined below.

Following leader vehicle of different speeds: the tendency of a cycle-rickshaw to follow a vehicle with a significantly different speed than itself (Budhkar and Maurya, 2017).

Following leader vehicle of different size: the tendency of a cycle-rickshaw to follow a vehicle with a significantly different size than itself(Budhkar and Maurya, 2017).

Tailgating: the tendency of driving too closely behind another vehicle (Madhu, Sivanandan,et al., , 2020)

Travelling abreast: the tendency of driving too closely adjacent to another vehicle (Madhu, Sivanandan,et al., , 2020)

Overtaking: the tendency of catching up and passing another vehicle (Madhu, Sivanandan,et al., , 2020)

Sub-variable-2:Non-lane discipline movement

Swerving: the tendency of changing direction abruptly (Madhu, Sivanandan,et al., , 2020)

Lane-splitting : Lane splitting is vehicle between lanes or rows of slow moving or stopped traffic moving in the same direction. It is sometimes called white-lining, or stripe-riding. This allows riders to save time, bypassing traffic congestion (Madhu, Sivanandan,et al., , 2020).

Sub-variable-3: Traffic rule-violation

Level of obeying traffic signs and signals: cycle-rickshaws pullers compliance or non-compliance with traffic signs and signals

Level of Erratic and impatient behaviour- cycle-rickshaws pullers tendency to make unpredictable movement especially when he is frustrated

3.5.4. Traffic congestion (Dependent variable)

Sub-variable 1: Temporal-delay based congestion

The temporal-delay congestion is measured by estimating the travel time during peak-period required to analyse the average vehicle speed along the annual hours of delay due to congestion. Temporal based indicators like travel time are used to determine average travel speeds in congested areas and attempts to locate the magnitude and sources of travel delay (Rao, 2012).

Travel time in peak period: time required to cover a distance when the demand of vehicles on the road is at the highest

Travel time in off-peak period: time required to cover a distance when the demand of vehicles on the road is at the lowest

Sub-variable 2: Spatial based congestion

To measure spatial based congestion, it is required to consider the spatial based indicators. Spatial Indicators measured as include level of service, congested lanes in Kilometre and Network connectivity Index. This measure concerns the amount and extent of congestion on roadways.

Level of service can is used as an indicator in this study to measure spatial based congestion. Therefore, volume-to capacity can be used as a measure of road performance through basic calculations using available data (Rao, 2012).

Level of service: Level of service is a qualitative measure used to relate the quality of motor vehicle traffic service. LOS is used to analyze roadways and intersections by categorizing

traffic flow and assigning quality levels of traffic based on categories from A (least congested) to F(most congested) (Deshpande, et al., 2010)

3.5.5. Operationalization Table:

The operationalization table below summarizes relevant concepts and definitions that were translated into variables, indicators and values essential for measuring the influence of cycle-rickshaw movement on traffic congestion. The chapter also presents the type of research design that was adopted for the study and highlights on the strategy, data collection methods, sample selection, and size as well as the techniques that were used in analysing the data collected. Further, the validity and reliability of the chosen research strategy and methodology are also presented in this chapter.

Table 1: Operationalization table

Concept	**Variable**	**Sub-variable**	**Indicator**
Heterogenous traffic flow	Movement of cycle-rickshaw pullers (Independent)	Movement amongst vehicle types	- *Following leader vehicle of different speeds* - *Following leader vehicle of different sizes*
		Non-lane discipline movement	- *Swerving* - *Lane-splitting*
Traffic management theory		Traffic-rule violation	- *Level of obeying traffic signs and symbols* - *Level of erratic and impatient behaviour*
	Traffic congestion (Dependent)	Temporal based congestion	- *Average travel time in peak and non-peak hour*
		Spatial based congestion	- *Level of service*

3.6. Limitations and Challenges:

3.6.1. Challenges:

The first challenge that I encountered was during the developmental stage of my conceptual framework and operationalisation table. In general traffic congestion is a widely researched topic in academia. However, research done in the past mostly included studies on traffic congestion from supply or demand side of transport management systems that include homogenous traffic characteristics. Most studies did not take into account the heterogeneousity of urban traffic systems in developing cities which was the area of research I was interested in. Nevertheless, the studies that I found were mostly focused on microscopic traffic modelling and simulations in heterogeneous conditions. Therefore, it was challenging for me to conceptualize and operationalize the movement of cycle-rickshaws from these studies. Secondly, during the data collection period, it was challenging for me to ask survey and interview respondents about the indicators derived for the study eg: tailgating, swerving, lane-splitting etc as these terminologies are too technical for the general public to understand. However, I tried to overcome this challenge by conducting a pilot survey and translating these technical terminologies into simple and causal choice of words which most likely define the phenomenon of these terminologies. Thirdly, because of the corona pandemic, a huge challenge was to survey and take interviews of the respondents in my study areas due to the protocols of maintaining social distancing rules. Another challenge was that I could not contact the respondents (vehicle drivers, rickshaw passengers, pedestrians and traffic police) through digital platforms because of two reasons specifically. The first one being that the respondents of my study belonged to the lower range of educational qualification, therefore many respondents could not read or write with the exception of few. The second reason was that many respondents belonged to the lower group of socio-economic characteristics which meant internet access was not available to them in their neighbourhoods. Therefore the only way to conduct surveys and interviews of respondents was to communicate with them verbally and upfront. However, I tried to overcome these challenges by ensuring that my research team was fully equipped with protective gears before collecting the responses from a distance. No physical papers were given to the respondents to avoid any exchange of papers between the research team and the respondent which could have increased the risk of contamination, hence, the questions were developed in an app which were verbally communicated to each of the respondent clearly to collect the answers and with adhering to social distancing rules.

3.6.2. Limitations:

The area of the study is Dhaka, the capital city of Bangladesh where three prominent and heterogeneous roads are chosen to carry out the research. The roads are Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Shahbag Square to Science laboratory (Dhaka Central), and Asad Gate to Mohammadpur Bus stop (Dhaka South). Hence, the respondents chosen for survey and interviews were only who regularly commuted along these roads during peak periods and off-peak both morning and evening times. The study collected data from both primary and secondary sources to answer the research

questions. Primary data collection sources include interview transcripts and survey results whereas secondary sources include academic literature, reports and google maps. Hence, data data was analysed in both qualitative and quantitative techniques. The aim of the study is to explain how cycle-rickshaw movement influence traffic congestion on the above mentioned roads in Dhaka city.

Cycle-rickshaw movement is the independent variable whereas traffic congestion is the dependent variable for the research question. The research uses the theories/concepts of heterogeneous traffic flow in developing cities which is not readily available in academic literature. Therefore the independent variable might include other sub-variables which would also influence traffic congestion in Dhaka city. Furthermore, for the dependent variable, only three indicators (average travel time in peak-period, average travel time in off-peak period and level of service) were used to measure the levels of congestion. However, the researcher is aware that traffic congestion measurement indicators are numerous but because of the limitation of time and resources, other indicators were not used in the study. In conclusion, the results of the study cannot be generalized on other areas of Dhaka city and the findings strictly focus on Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association road (Dhaka North), Shahbag Square to Science laboratory road (Dhaka Central), and Asad Gate to Mohammadpur Bus stop road (Dhaka South) of mega-city Dhaka city. Not to mention, the most pressing issue for the researcher was the corona pandemic. Because the researcher observed that due to the corona pandemic, the traffic situation in the study areas were different than usual times which could have impacted the data collected to a certain extent as at times when the survey and interviews were conducted, movements were a little restricted than pre-pandemic times.

Chapter 4: Presentation of data and analysis

4.1: Introduction

This chapter seeks to present the findings of the data gathered from the field. The chapter begins with a brief description of the case narrating the characteristics of the chosen study areas followed by the characteristics of questionnaires and interview respondents as the unit of study. The chapter is later followed by the findings presented according to the order of variables and sub-variables along with their indicators as discussed in chapter 3 to analyse all the data collected from questionnaires, interviews, secondary sources and statistical results.

4.2: Description of the Case

This research is based on traffic congestion on three prominent and busy heterogeneous roads in Dhaka city where traffic flow consists of varied number of motorised and non-motorised vehicles. The three roads are located in the Northern, Central and Southern parts of Dhaka city in terms of administrative zoning. Two significant points/landmarks/signals were located in each road to analyse the influence of cycle-rickshaw movement on congestion between these two points/landmarks/signals specifically. The roads are identified as Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Asad Gate to Mohammadpur Bus stop (Dhaka Central) and Shahbag Square to Science laboratory (Dhaka South). The roads are considered to be some of the most congested heterogeneous roads in Dhaka North, Central, and South zones as they belong to important neighbourhoods consisting mixed land use facilities like popular educational institutions, commercial centres, offices, hospitals and residential buildings. To analyse the influence of cycle-rickshaw movement on traffic congestion in these three neighbourhoods, the roads selected were deliberately similar in terms of length. However, the neighbourhoods of the three roads vary in terms of land use patterns, connectivity and socioeconomic characteristics of the inhabitants which has been found to be a major factor between the levels of traffic congestion on the three roads as discussed later in the end of this chapter.

Table 2: Length of Study area roads

Administrative zone	Study route	Length in km
Dhaka North	Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association	1.6 km
Dhaka central	Asad Gate to Mohammadpur Bus stop	1.3 km
Dhaka South	Shahbag Square to Science laboratory	1.4 km

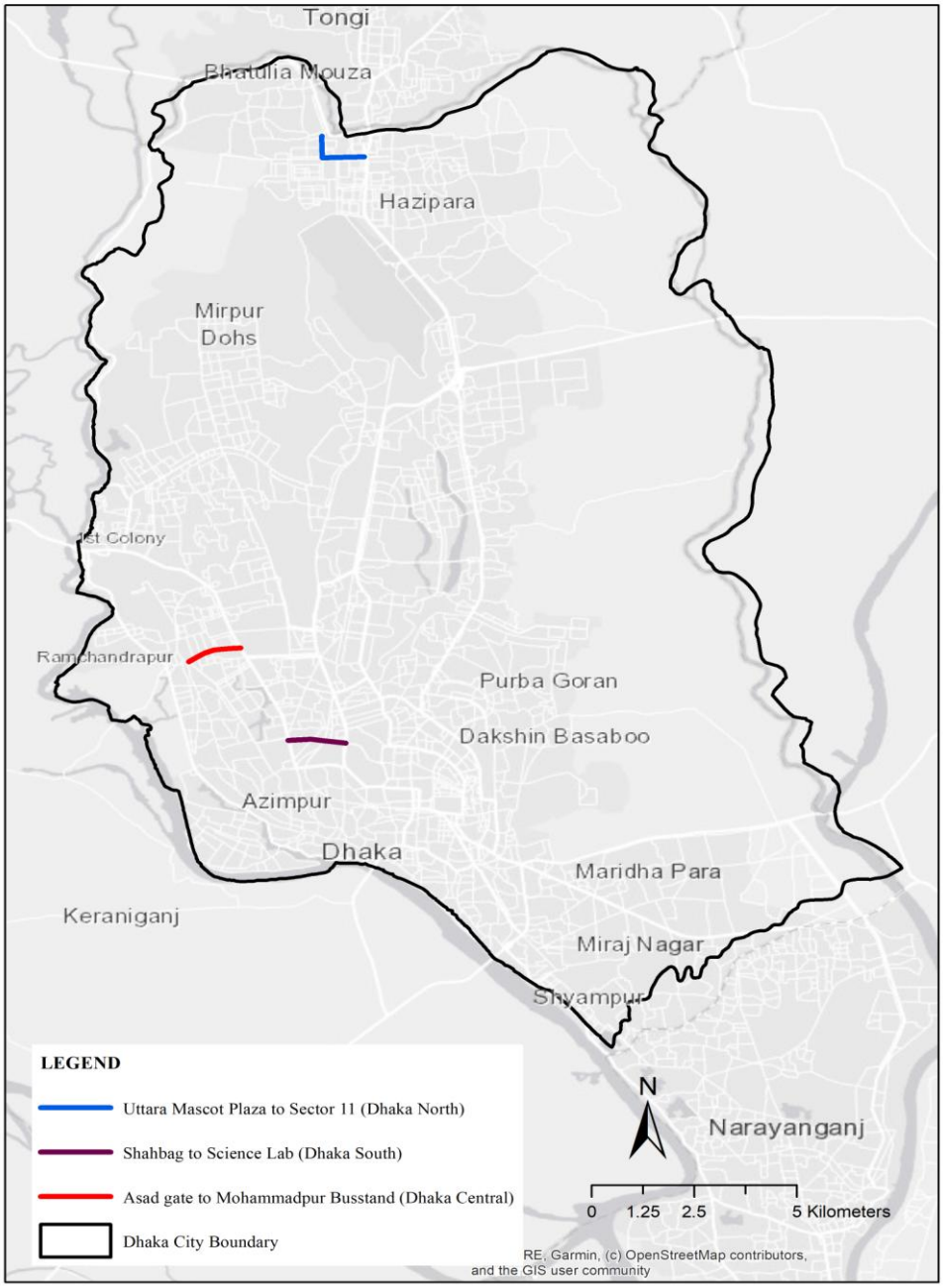


Fig 5: Map of Dhaka city showing study areas

Traffic congestion in Dhaka city are considered to be emerging from multi-dimensional causes, however over the years many researchers have stated that the main causes of traffic congestion in Dhaka city include poor execution of traffic code of practice, fragmented responsibilities between too many regulatory authorities, violation of traffic rules by

vehicle drivers, too many non-registered non-motorised vehicles, poor city and transportation planning, inadequate traffic management resources, lack of mass public transportation system and uncontrollable growth of vehicle ownership (Ahmed, 2017).

Apart from being the administrative capital, Dhaka is considered to be the economic hub of the country besides being the cultural and political centre. In recent times, Dhaka is responsible for a fifth of the country's gross domestic product (GDP) (Wee, 2018). This attracts massive number of people to migrate to Dhaka annually. However, Dhaka city has failed to meet this growing demand of effective transportation management especially, in terms of providing adequate public mass transportation services. Due to a lack of this, cycle-rickshaws are a popular mode of transportation which for its mismanagement and lack of discipline has given rise to excessive traffic congestion. It is in this view that the research was undertaken to investigate how cycle-rickshaw movement influence traffic congestion on Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Asad Gate to Mohammadpur Bus stop (Dhaka central) and Shahbag Square to Science laboratory (Dhaka South), and) roads in Dhaka city using questionnaires, interviews and secondary sources as data collection methods.

4.3: Characteristics of Respondents

4.3.1. Interviews:

To select the interview respondents, random probability sampling was used where pedestrians, cycle-rickshaw passengers, traffic police and vehicle drivers regularly commute and patrol in the three study areas. The interviewee selection was carefully decided in order to avoid collecting repetitive information already collected from a large sample size of 400 vehicle drivers via surveys. For this reason, three traffic police officers were selected from the three study areas for the first set of unit of observation in order to achieve insights regarding the state of traffic congestion of Dhaka city in the study areas. Furthermore, passengers who travel by cycle-rickshaws on a regular basis were selected as the second set of key informants in order to achieve information from personal journeys since they have been the most closest to the cycle-rickshaw pullers in terms of proximity. For the third set of unit of observations, vehicle drivers were selected in order to get an in-depth understanding of how cycle-rickshaw movement influences neighbouring vehicles in traffic streams. However, it is often observed in Dhaka city that vehicle drivers and cycle-rickshaw pullers get into verbal and physical exchange of abuses due to conflicts occurred during commuting on roads which may influence them to develop negative perceptions about each other. For this reason, pedestrians were selected as the final set of unit of observations in order to achieve insights from a neutral and third party perspective. The final list of interviewed respondents comprised of 3 traffic police officers, 2 cycle-rickshaw passengers, 2 vehicle drivers and 2 pedestrians from the three study areas which make the total of 9 respondents as shown in the table below.

Table 3 : Interview respondents' distribution

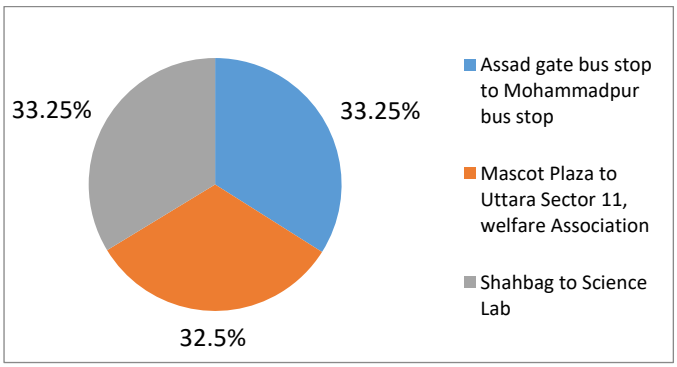
Organizations	Number
Traffic police	3
Cycle-rickshaw passengers	2
Vehicle drivers	2
Pedestrians	2
Total	9

4.3.2. Questionnaires:

Random probability sampling was used to select the survey respondents for questionnaires. Questionnaires were applied to collect data from vehicle drivers who use Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Shahbag Square to Science laboratory (Dhaka Central), and Asad Gate to Mohammadpur Bus stop in Dhaka city (Dhaka South). The sample size of questionnaires was based on the total number of registered vehicles of Dhaka city. The total number of registered vehicles is 166,840 and the sample size is 400. In all the three study areas, about 133 responses were collected each.

To get a fair view of the representation of the sampled population of the study the age, occupation and type of vehicle driven by the respondents of the sample were asked of all. The figures below show the summary of the characteristics of the surveyed respondents obtained from the descriptive statistical analysis conducted.

Fig 6: Distribution of survey respondents per roads



Total number of respondents= 400

Fig 7: Distribution of survey respondents per age group

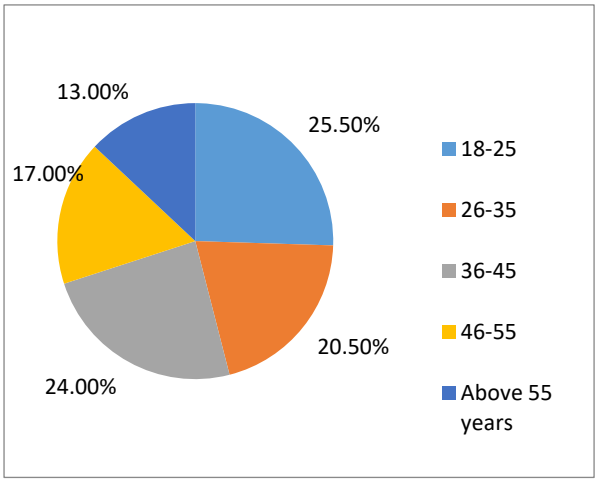
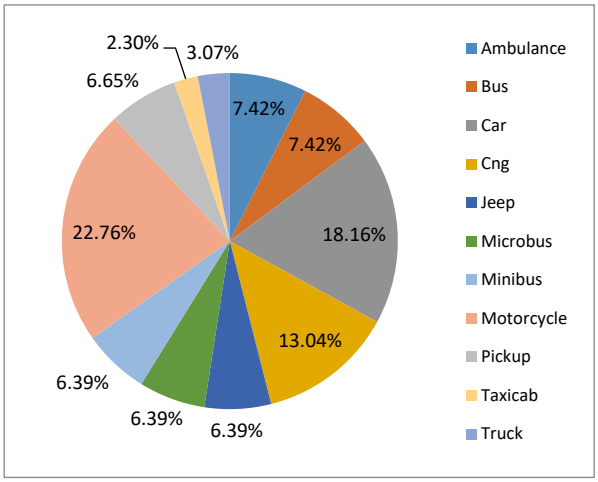


Fig 8: Type of vehicle driven by surveyed drivers



4.4: Presentation and analysis of data for variables and sub-variables

In the section below, information and data collected is presented and analysed according to the order of the ivariables, sub-variables as well as indicators following the order of the operationalization table in chapter 3 and the conceptual framework in chapter 2. The analysis of each variable and sub-variable starts with the findings from questionnaire responses followed by interview responses. The responses from interviews were named from R1 to R9 based on the codes generated from Atlas ti. Lastly, secondary sources and academic literature reviewed were used to validate the summary of the findings collected from the questionnaires and interviews for the purpose of triangulation. A description of the outcome from the above-mentioned sources was presented at the end of each variable where the sub-variables and indicators were analysed separately wherever possible. The section starts with the data presentation of the independent variable first followed by the dependent variable.

4.4.1: Movement of cycle-rickshaws (Independent variable)

The independent variable in this study, Movement of cycle-rickshaws, as explained in the previous chapters is clustered in 3 sub-variables namely, movement amongst vehicle types, non-lane discipline movement and traffic-rule violation. Each sub-variable was analysed separately following the order of presenting the data collected from questionnaires and interviews of all the indicators first and then it was further analysed by the findings from the secondary sources wherever applicable.

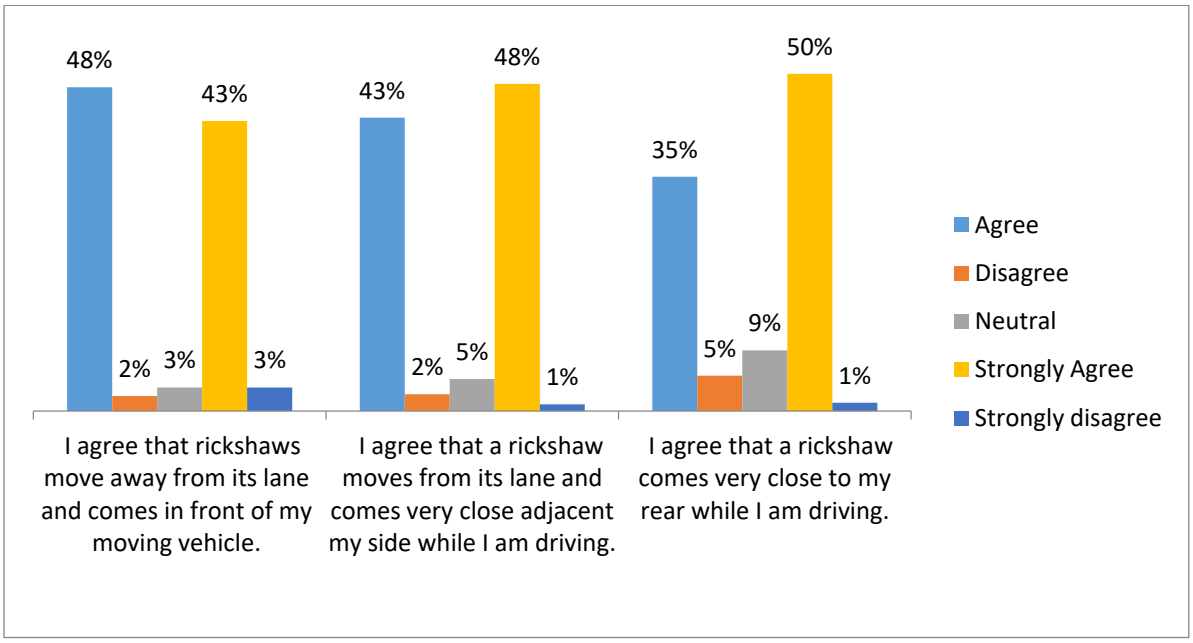
4.4.2: Movement amongst vehicle types (Sub-variable-1)

2 indicators were used for this sub-variable. The indicators were termed as *following leader vehicles of different speeds* and *following leader vehicles of different sizes* respectively by cycle-rickshaws on Dhaka North, Dhaka Central and Dhaka South. Survey responses and

summary of interview responses for the two indicators, *following leader vehicle of different speeds (indicator 1)* and *following leader vehicles of different sizes (indicator 2)* were presented and analysed and corroborated with secondary sources for each indicators separately. The descriptions of the analysis are presented below.

Following leader vehicles of different speeds (indicator 1)

Fig 9: Survey responses for all three study areas combined



Total number of respondents=400

Cycle-rickshaws' level of ***following leader vehicle of different speeds*** were estimated by surveying vehicle drivers of different speeds about their agreement or disagreement of cycle-rickshaws tendency of conducting three types of movements. The movements are known as tailgating, travelling abreast and overtaking. Tailgating, travelling abreast and overtaking are three different types of movement a vehicle will conduct when it is about to follow a leader vehicle of different speeds. Individual definitions of the different types of movements are given below.

Tailgating: the tendency of driving too closely behind another vehicle (Madhu, Sivanandan and Srinivasan, 2020)

Travelling abreast: the tendency of driving too closely adjacent to another vehicle (Madhu, Sivanandan and Srinivasan, 2020)

Overtaking: the tendency of catching up and passing another vehicle (Madhu, Sivanandan and Srinivasan, 2020)

The questions were designed in a simplified manner for vehicle drivers as tailgating, travelling abreast and overtaking are technical terms which could have been difficult for the general public to grasp the concept of. Therefore the questions asked were as, I agree that rickshaws come very close to my rear while I am driving (tailgating), I agree that rickshaws

come very close adjacent to my side while I am driving (travelling abreast) and I agree that rickshaws come in front of my moving vehicle while I am driving (overtaking) by cycle-rickshaws. Questionnaires were distributed to a 400 drivers of varied vehicular speeds to ask about their perceptions of the above questions where 35 % and 50 % respondents chose 'Agree' and 'Strongly Agree' for tailgating, 43 % and 48% respondents chose 'Agree' and 'Strongly Agree' for travelling abreast and 48% and 43 % respondents chose 'Agree' and 'Strongly Agree' for overtaking respectively. The results showed strong agreement from the respondents for the three kinds of following leader vehicle movements by cycle-rickshaws. These results are justified by the observations of authors Budhkar and Maurya (2017) and Sarlas and Papathanasopoulou a (2013) who mentioned in their studies that the most common characteristic of a heterogeneous traffic flow is that a single vehicle follows multiple leader vehicles of different speeds and each manoeuvre varies significantly from one another. The survey responses are further corroborated with the responses from 9 key informants which are discussed below.

Table 4: Frequency distribution table for following leader vehicle of different speeds (indicator 1)

Sub-variable	Indicators	Summary of interview responses	Frequencies
Movement amongst vehicle types	Following leader vehicle of different speeds	Rickshaws being a slow moving vehicle often comes in front of a faster moving vehicle for example, bus, motorcycles and private cars when the traffic is stopped. This slows down the vehicles behind the rickshaw for which they cannot cross the intersections in due time.	3 **
		Rickshaws move very slowly and cannot be overtaken as it might increase the risk of accidents on busy roads. Therefore the speed of the vehicles behind the rickshaw is reduced.	1 *
		Large number of rickshaws often stop in front of vehicles to pick up passengers in peak periods. Because of their slow speed, they cannot move fast after they have picked up passengers.	3 **
		Due to the slow speed of rickshaws, it delays other vehicles in reaching their destinations.	1*
		The number of rickshaws are increasing day by day which are responsible for traffic congestion on the roads	1*

*Total number of respondent=1

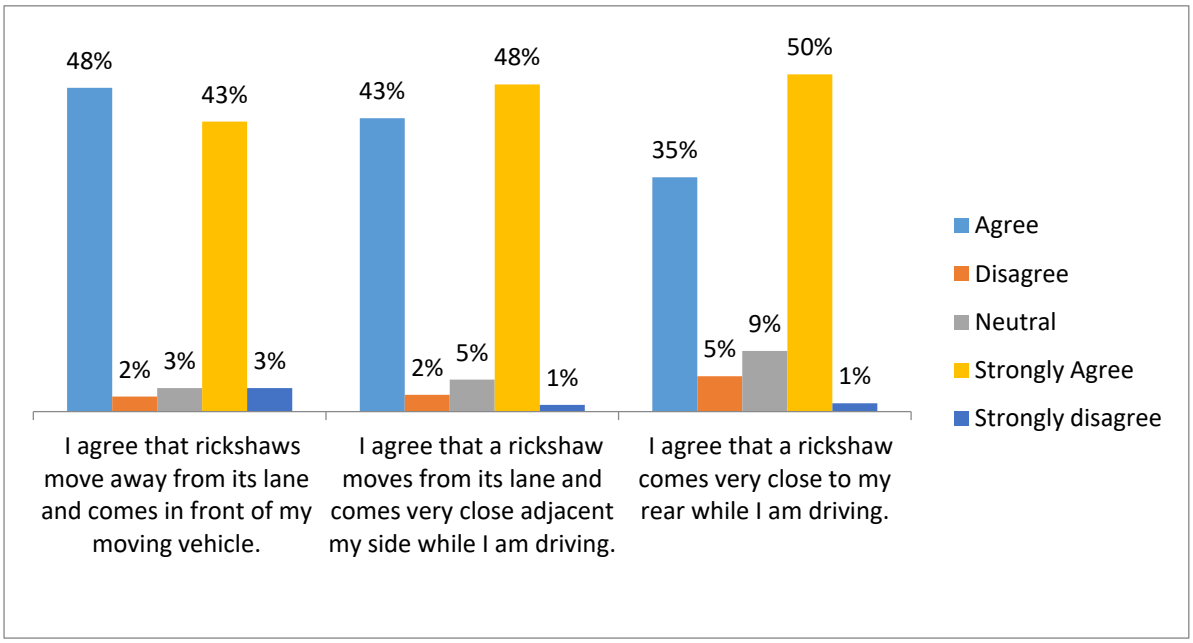
**Total number of respondents=9

For following leader vehicle of different speeds, 3/9 interviews mentioned that, cycle-rickshaws often moves in front of motorised vehicles for example, buses, motorcycles and private cars when the traffic is stopped. This causes the motorised vehicles behind the cycle-rickshaw to miss crossing the intersection in due time when the signal turns green. This phenomenon could occur because of the fact that cycle-rickshaws are slower in speed than motorised vehicles. Therefore, when it follows and arrives in front of a motorised fast moving vehicle when the traffic is stopped, it tends to act as an obstacle for the motorised vehicle to move ahead when the signal turns green resulting in a delay to cross the intersections. This finding could be justified by authors Khan and Maini (1999) who mentioned in their study that since cycle-rickshaws are being operated by human labour, it tends to have significantly lower speeds than its neighbouring vehicles and therefore its manoeuvring capabilities could

cause disruptions for other fast moving motorised vehicles. Furthermore, authors Sarlas, Papathanasopoulou and Antoniou (2013), also mentioned that in a heterogeneous traffic flow, the subject vehicle gets numerous opportunities to follow a leader vehicle due to the complexity of the traffic flow even though significant difference exist between the speeds of the subject and the leader vehicle. 3/9 interviews also mentioned that large numbers of cycle-rickshaws after following the vehicles move in front of fast moving vehicles when the traffic is stopped and when the traffic starts moving, stop randomly at places to pick up passengers. The interviewee, (R:4) added in respect to his statement that when rickshaws do this, they fail to move fast and clear way for other vehicles right after they have picked up passengers which causes traffic congestion on the roads. This could be because of the fact that since cycle-rickshaws are slower in speed and maneovered by human labour, they fail to accelerate back after they have picked up passengers. This delay in acceleration delays them in moving ahead in time, resulting in a delay for all other motorised vehicles behind the cycle-rickshaws. Increase in travel time influences decrease in average speed for other fast moving vehicles on the road which causes them to miss crossing the intersections in due time. This interpretation is further corroborated by Khan and Maini (1999) in their study mentioned a similar observation that in heterogeneous traffic conditions, since different vehicles have different manoeuvring capabilities, hence their acceleration capabilities are also different. Lastly 1 interviewee mentioned that cycle-rickshaws on the road cannot be overtaken by other fast moving vehicles because of their slow speed, as it might increase the risk of causing accidents during peak hours in busy roads.

Following leader vehicle of different sizes (indicator 2)

Fig 11: Survey responses for all the three study areas combined



Total number of respondents=400

Cycle-rickshaws' level of ***following leader vehicle of different sizes*** was estimated using the same survey data as the above indicator since both the indicators of following leader vehicle of different sizes and following leader vehicle of different speeds correlate with each other. Since the vehicles of the 400 drivers vary in terms of both size and speed, the use of the same data for both the indicators for survey responses seem to be appropriate. However, the indicator was analysed separately with interview responses to understand the influence on leader vehicle of different sizes when followed by cycle-rickshaws. As explained above for indicator 1 and as shown the figure 10 above the survey results show strong agreement for cycle-rickshaws level of overtaking (I agree that rickshaws move away from its lane and comes in front of my moving vehicle), level of travelling abreast (I agree that cycle-rickshaws moves from its lane and comes adjacent my side while I am driving) and level of tailgating (I agree that a rickshaw comes very close to my rear while I am driving). According to (Sarlas, Papathanasopoulou and Antoniou, 2013), in heterogeneous traffic flow, the differences in sizes of vehicles also have an impact on the overall traffic flow.

Table 5: Frequency distribution table for following leader vehicle of different sizes (indicator 2)

Sub-variable	Indicator	Summary of interview responses	Frequency
Movement amongst vehicle types	Following leader vehicle of different sizes	Rickshaws take advantage of gaps between two other large vehicles like buses. For this reason, when the signal turns green, the rickshaw cannot move fast enough as the large vehicle is in front of it, also causing the other large vehicle behind it to reduce its speed.	5**
		Rickshaws are one of the smallest vehicles on the roads compared to others. When a rickshaw comes in front of a bigger vehicle like bus, it causes a disruption on the flow of the traffic as the bigger vehicle cannot overtake rickshaws due to a risk of causing accidents.	4**

*Total number of respondent=1

**Total number of respondents=9

For level of following leader vehicle of different sizes, 5/9 interviews mentioned that, cycle-rickshaws being a small vehicle often take advantage of gaps between two other large vehicles like buses. The interviewee, (R: 2) added in respect to his statement that because of this, when the signal turns green, the rickshaw cannot move fast enough like the large vehicle in front of it, causing the other vehicle behind the cycle-rickshaw to reduce its speed. This finding can be justified with the observation of authors Madhu, Sivanandan and Srinivasan (2020) and (Sarlas, Papathanasopoulou and Antoniou, 2013) vehicles in heterogeneous conditions can place themselves anywhere in the traffic stream depending on availability of gaps between vehicles. The differences in sizes of vehicles have an impact on the overall traffic flow. The authors mentioned that small sized vehicles occupy available lateral and longitudinal gaps on the road space between large vehicles in traffic stream. Additionally, 4/9 interviewees mentioned that as cycle-rickshaws are one of the smallest vehicles on the roads compared to others, when it comes in front of a bigger vehicle like a truck, it cannot be overtaken by other bigger vehicles as the bigger vehicle would require more space to overtake it. Therefore, the bigger vehicle tends to remain at rest, reducing its speed

excessively. This is again corroborated by (Munigety and Mathew, 2016), that the size of a vehicle affects the amount of space it occupies, as well as its turning capability, defining the lateral movement behaviour of a driver. For example, a heavy vehicle like truck offers less flexibility to its driver while manoeuvring on a traffic stream than a smaller vehicle like motorbike or cycle-rickshaw.

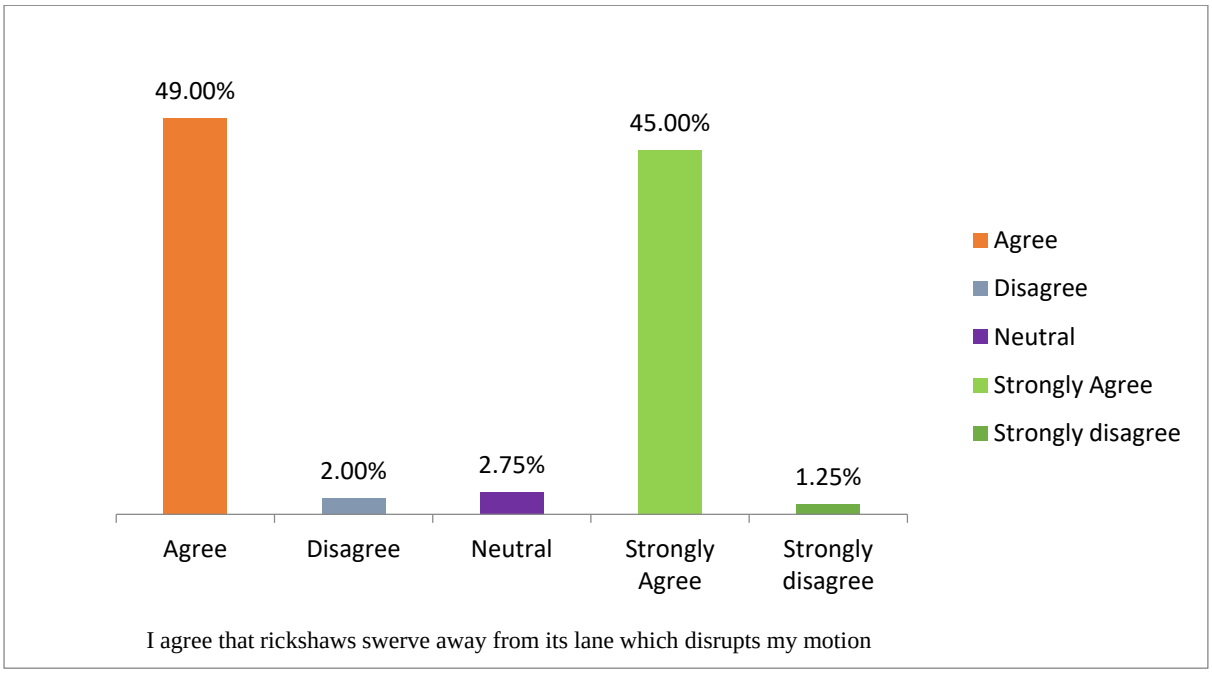
To sum up for these indicators of following *leader vehicle of different speeds* and *following leader vehicles of different sizes*, based on the findings from questionnaires, interviews further corroborated by available literature, it is evident that cycle-rickshaws follow leader vehicle of different speeds of which are much faster and they follow leader vehicles of different sizes including which are larger. This presence of different vehicle types of both speeds and sizes impose multiple physical and psychological effects on the surrounding vehicles and their drivers, resulting in either an increase or drop in the roadway capacity (Munigety and Mathew, 2016).

4.4.3: Non-lane discipline movement

Two indicators were used on this sub-variable to know the level of non-lane discipline movement of cycle-rickshaws commuting in Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Shahbag Square to Science laboratory (Dhaka South), and Asad Gate to Mohammadpur Bus stop (Dhaka central). The two indicators are termed as *swerving, and lane-splitting.* The data for these two indicators were collected from interviews and questionnaires which were later corroborated by academic literature in order to draw conclusions from the findings.

Swerving(indicator 1)

Fig 13: Survey respondents of entire study area



Level of swerving by cycle-rickshaws were further asked to 400 vehicle drivers about their agreement or disagreement with the statement saying, ‘‘I agree that rickshaws swerve away from its lane which disrupts my motion,’’ where 45 % and 49 % chose ‘‘Strongly Agree’’ and ‘‘Agree’’ which shows a very high agreement of level of swerving of cycle-rickshaws. The findings from the questionnaires could be corroborated with the authors, (Munigety and Mathew, 2016) who have identified that due to weak lane discipline, vehicle drivers may exhibit peculiar patterns such as maintaining shorter headways and swerving. The authors added that in heterogeneous traffic conditions, drivers tend to maintain shorter following distances compared to lane-based conditions as they have options of tailgating a leader vehicle by aligning to one of its lateral edges. When the vehicle driver realises that he has shortened the safety gap and sees a possibility of colliding with the leader vehicle, it swerves off from its current position.

Table 6: Frequency distribution table for swerving

Sub-variable	Indicators	Summary of interview responses	Frequency
Movement amongst vehicle types	Swerving	Rickshaws would suddenly move its head/front on the sideways shifting from its lane. Because of this, the vehicle coming from behind the rickshaw often have to immediately hard brake or reduce speed in order to avoid hitting the rickshaw. At night-time, this behaviour becomes more dangerous because of limited visibility.	5**
		Rickshaws would often swerve away abruptly which has made the vehicle to hard brake and often hit the rickshaw with passengers.	2**
		Once the vehicle has reduced its speed to avoid hitting the rickshaw, it gets difficult for many vehicles to again accelerate back especially for two wheelers like motorcycles.	1*
		Often the vehicle behind a cycle- rickshaws have to brake immediately because of rickshaws’ swerving without giving any signals to the vehicles behind it which often causes the vehicle behind to stop suddenly or hit the vehicle.	2**

*Total number of respondent=1

**Total number of respondents=9

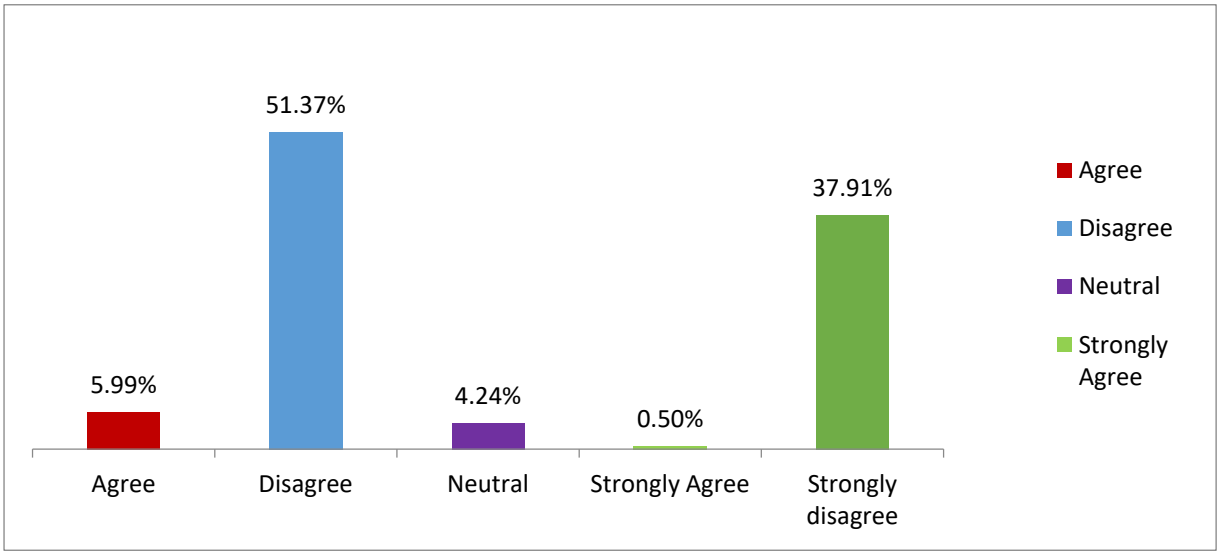
The results from the interviews show that 5/9 interviewees mentioned that cycle-rickshaws often tend to move away abruptly from its lane by moving their heads first. Because of this, the vehicle coming from behind have to immediately reduce their speed or give hard breaks in order to avoid hitting the cycle-rickshaw. The interviewee, (R: 5) also mentioned that this kind of behaviour by cycle-rickshaws get more dangerous at night-time than daytime as the vehicle behind the rickshaw cannot see this abrupt swerving usually because of the size of the rickshaw which is very small and at night-time there is less visibility. On the other hand, 2/9 interviews mentioned that since the vehicles behind the cycle-rickshaws often encounter this abrupt swerving, it does not offer them enough time to give indicators to other vehicles coming behind them before they need to decelerate, brake hard or change directions. This often causes dangerous situations like collisions. The findings above can be corroborated by

authors Khan and Maini (1999) who suggested that rickshaw pullers often make an immediate or abrupt decision to change direction or swerve away even if the traffic flowing is in one particular motion. This change in manoeuvrability in heterogeneous traffic creates chaos and disruption for not only the vehicles that are surrounding it but also to the ones that are behind it. Moreover, 1 interviewee mentioned that even if the vehicles behind the cycle-rickshaws manage to reduce their speed in due time, it gets very difficult for the vehicles to accelerate back especially for two-wheelers like motorcycles. The interviewee, (R:2) mentioned that because of this happening all the time, the average speed of the vehicle decreases to a great extent. Finally, 2 interviewee mentioned that many times because of the abrupt swerving of rickshaws, there has been collisions between a fast moving vehicle and a cycle-rickshaw carrying passengers with no fault of the vehicle driver. The interviewee mentioned that these kind of situations gets frustrating for everyone on the road.

''At times my car has hit cycle-rickshaws and the rickshaw fell down with the passengers and my car got a dent. We have to constantly be alert even if we maintain a steady lane but rickshaws do not maintain that. In these kind of situations, I get very angry as I have no fault of my own. But I cannot say much to the rickshaw pullers as they are uneducated and I feel bad for the passengers who fell off and got hurt from the rickshaws. The whole situation gets very messy and frustrating. '' (R:2)

Lane-splitting (indicator 2)

Fig 15: Survey respondents of entire study area



I agree that rickshaws do not change their lanes and move between vehicles when the traffic is stopped

Level of lane-splitting by cycle-rickshaws were asked to 400 vehicle drivers with the statement that ' I agree that rickshaws do not change their lanes and move between vehicles when the traffic is stopped.' It must be emphasized that this statement was purposely stated as a positive statement to achieve a reliable and unbiased perception by vehicle drivers. However, the 37.91 % chose 'Strongly Disagree' and 51.37 % chose 'Disagree' for 'I agree

that rickshaws do not change their lanes and move between vehicles when the traffic is stopped.' The results from the survey responses can be corroborated with the fact that according to (Agarwal and Lämmel, 2015), in congested part of links, smaller vehicles like motorbikes and bikes do not stop at the end of queue. Instead, they move continuously across the gaps between the stationary congested vehicles. Due to easier manoeuvrability of smaller vehicles, these vehicles pass across the gaps between the stationary or almost stationary vehicles. This is easily done by them because of their flexibility in manoeuvring and their small size. The authors also added that these vehicles are non-sensitive to the width of the road but they affect the flow of other vehicles remarkably.

Table 7: Frequency Distribution table of level of lane-splitting

Sub-variable	Indicators	Summary of interview responses	Frequency
Movement amongst vehicle types	Lane splitting	Rickshaws being a small sized vehicle, often try to move ahead between available spaces between vehicles. Because of this, they cannot estimate the available space and often hit and damage the vehicle.	2**
		Rickshaws often take position between very small space between two vehicles and wait there for the traffic signal to turn green. For this reason, the vehicle behind the rickshaw fail to accelerate when the signal turns back to green and fails to cross the signal in due time.	2**
		Rickshaws take position between available gaps when the traffic is stopped, to avoid being at rest, because they think by doing this, they can reach their destination faster. When many rickshaws do this, they tend to spread randomly away from their lanes all over the road. This causes a chaos and disorder in the road and influences other vehicles like cars, buses and cng to shift from their lanes as well, causing an overall reduction of average traffic speed.	5*

*Total number of respondent=1

**Total number of respondents=9

The results from the interviews show that 5/9 interviews mentioned that cycle-rickshaws take position between available gaps between neighbouring vehicles when the traffic is stopped and try to move in-between vehicles to avoid being at rest. One of the interviewees mentioned that when many rickshaws do this, they tend to spread randomly away from their lanes all over the road. This causes a chaos and disorder in the road and influences other vehicles like cars, buses and cng to shift from their lanes as well, causing an overall reduction of average traffic speed. This phenomenon can be corroborated by authors (Parsuvanathan, 2015) who mentioned that small vehicles in developing countries assume any free space to be virtual lanes and try to move through it to avoid being stopped at traffic for long hours. The interviewee, (R:5) added in respect to this statement that rickshaws do this because they are impatient and want to reach their destination as soon as possible. The sooner a rickshaw reaches its destination to drop off or pick up passengers, the better the business for the rickshaw puller. Khan and Maini (1999) explained as a rickshaw-puller manoeuvre in order to follow the target direction which is the direction in which they intend to move on to reach their target destination, he will often try to achieve the easiest path to reach the destination in least travel time even when there is adverse traffic congestion. Since quicker way to the

destination means more revenue, he will try to manoeuvre between available gaps of stationary vehicles using all scopes causing a chaos and disorder in overall vehicular traffic movement. Moreover, 2/9 interview responses mentioned that as cycle-rickshaws move in between lanes and try to move ahead when the signal is stopped, the vehicles behind the cycle-rickshaws fail to accelerate back when the signal turns green and cannot cross the signal in due time. On the other hand, 2 interviewees also mentioned that because of cycle-rickshaws tendency to position itself between neighbouring vehicles to move ahead when the traffic is stopped, they sometimes, fail to estimate the minimum space required for the rickshaw to position itself between the vehicles. For this reason, many times, a cycle-rickshaw is seen to hit and cause damage to the vehicle when it is trying to position itself between available gaps of vehicles. Madhu, Sivanandan and Srinivasan (2020) mentioned that in mixed traffic streams, where the vehicles are restricted to perform free manoeuvres during congestion, two and three-wheelers use their opportunity of flexible manoeuvring and size to move through the gaps available between the vehicles which gives them the benefit of operating under maximum capacity to reach their destination. This behaviour leads to overall chaotic vehicular movement patterns of the traffic stream and can cause adverse traffic congestion and accidents.

''When we are stuck in traffic, since the size of the rickshaws are small they often move sideways in between vehicles. Sometimes, they move in-between so small spaces that it feels that any time the rickshaws will hit my car and make a dent. It happened once with me when the rickshaw did not estimate the space available and tried to move in between the space. Hence, it hit my side mirror and scratched the body of my car.''(R:2)

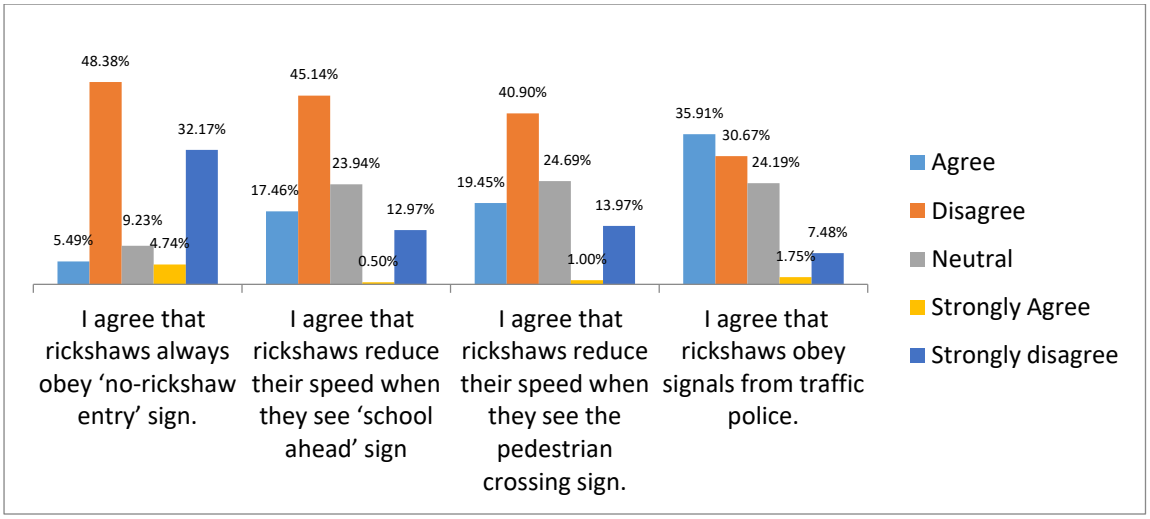
''Suppose the rickshaw came and covered the space between the vehicles, after 30/40 minutes when the signal turns green and I want to accelerate my vehicle forward, I cannot do this because the rickshaw obviously cannot accelerate. Even if they slowly disperse away and give us space but by then its obviously too late. Some times it also happens that I get late again and the signal has turned from red to green and back to red but I could not cross the signal. I could not even move a little bit ahead. Its gets so frustrating.''(R:3)

4.4.4: Traffic-rule violation (Sub-variable:3)

Two indicators were used for this sub-variable to know the level of traffic-rule violation of movement of cycle-rickshaws commuting in Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Shahbag Square to Science laboratory (Dhaka South), and Asad Gate to Mohammadpur Bus stop (Dhaka central). The two indicators are termed as *knowledge about traffic signs and symbols* and *erratic & unpredictable behaviour*. The data for these two indicators were collected from questionnaires and interviews which were later corroborated by academic literature in order to draw conclusions from the findings.

Level of obeying traffic signs and signals (indicator 1)

Fig 16: Survey results for level of obeying traffic signs and signals



Level of obeying traffic signs and signals by cycle-rickshaw were asked to 400 vehicle drivers in a survey. Vehicle drivers were particularly asked about three different signs ('no-rickshaw' entry sign, 'school ahead' sign, 'pedestrian crossing' sign) stating, 'I agree that rickshaws always obey no-rickshaw entry sign', 'I agree that rickshaws reduce their speed when they see school ahead sign', and ' I agree that rickshaws reduce their speed when they see pedestrian crossing sign'. 48.38 % and 32.17 % chose Disagree and Strongly Disagree for no-rickshaw entry sign. For cycle-rickshaws obeying of 'school ahead' and 'pedestrian crossing' signs, 45.14 % and 40.90 % chose Disagree. Out of all the three signs, the combined percentage for Strongly Disagree and Disagree is higher for cycle-rickshaws obeying of no-rickshaw entry sign. The survey responses were corroborated with interview respondents were 3 out of 9 interviewees mentioned that cycle-rickshaws do not obey no-entry rickshaw sign which will be further discussed below.

Additionally, the second part of the indicator, level of obeying traffic signals were also surveyed to 400 vehicle drivers with the statement 'I agree that rickshaws obey signals from traffic police.' The survey responses revealed that 30.6 % chose Disagree whereas 35.91 % chose Agree. The difference in opinion for level of obeying traffic signals exist due to the fact that traffic signals are given by the traffic police in Dhaka city and 35 % respondents who chose Agree could be because of the fact that respondents believe that rickshaw pullers obey traffic signals due to the fear of constantly being fined or confronted by the traffic police.

Table 8: Frequency Distribution table of obeying traffic signs and signals

Sub-Variable	Indicator	Summary of interview responses	Frequency
Traffic rule violation	Level of obeying traffic signs and symbols	Rickshaw pullers constantly break traffic rules. They try to cross the signals even when the light is not green especially when there is no traffic police or at night when he is looking elsewhere. They are constantly being fined	4**
		Rickshaw pullers do not understand the traffic signals properly and hence they do not follow them.	2**

		Even though rickshaws are prohibited on the roads, they enter the roads from adjacent secondary roads where rickshaw movement was prohibited. Most of them do not understand the traffic signs properly.	3**
		Rickshaw pullers are trying to obey traffic laws now as they are afraid of the traffic police fining them.	2**

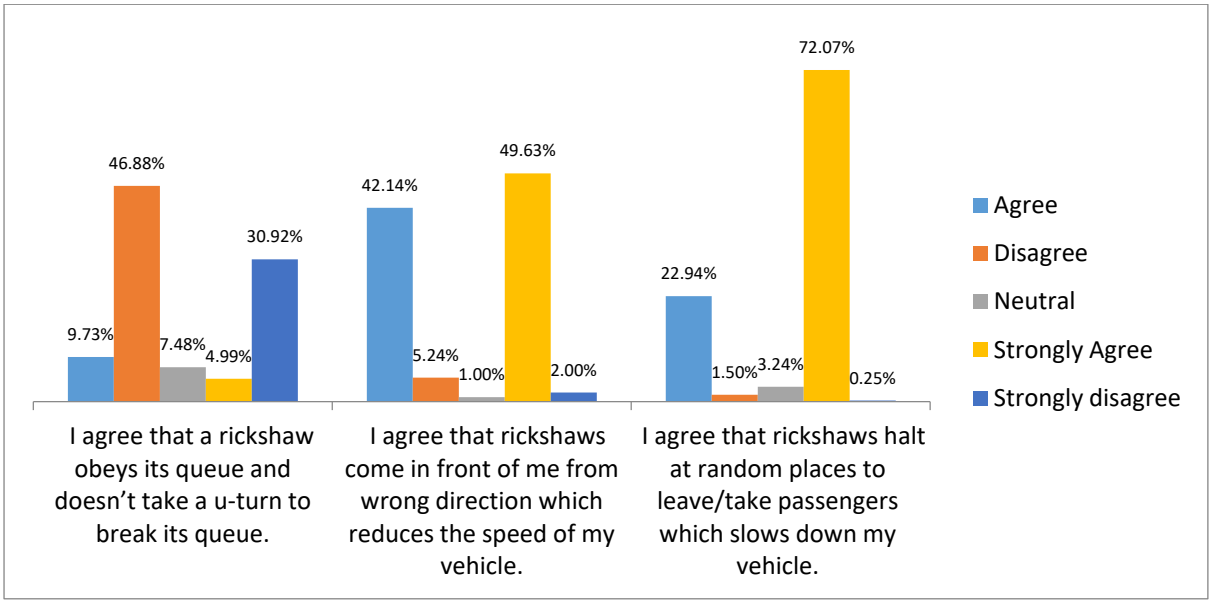
****Total number of respondents = 9**

4/9 interviewees mentioned that rickshaw pullers constantly break traffic rules. They try to cross the signals even when the light is not green especially when there is no traffic police patrolling or at night when they are distracted and because of this they are constantly being fined. This finding is corroborated with the literature that according to (Ibadan, 2020) traffic law violations by vehicle drivers tend to be more in the evening peak period than the morning peak period as vehicle drivers take advantage of violating laws in the darkness. On the other hand, 2/9 interviews also mentioned that cycle-rickshaw pullers are now trying to obey traffic laws more than ever as they are afraid of the traffic police fining them. As explained above, survey responses also corroborated that 35.91 % agreed that cycle-rickshaws obey traffic signals because respondents believe that fear of being fined by the traffic police motivates the rickshaw pullers to obey signals from them. However when asked to 3 traffic police in the three study areas about cycle-rickshaws tendency of obeying traffic signals, they claimed that rickshaw pullers do not understand the signals and they face difficulties in handling them every day.

The results from the interviews show that 3/9 interviewee further went to mention that a number of rickshaws continue to enter in the road from adjacent secondary roads where rickshaw entry is prohibited. Even though the rickshaw movement is prohibited on these roads, drivers often see rickshaws coming from these roads which causes disruptions of traffic flow especially if the rickshaw comes in front of a motorised vehicle while it is entering. 2/9 interviewees also mentioned that majority of cycle-rickshaw pullers according to his experience, do not even understand the traffic signs and signals by the police and for this reason they are constantly disobeying them. According to (Sohel, 2006), traffic rule violations influence problems in the smooth traffic flow of urban traffic resulting to negative consequences if not properly managed. Secondary data reveals that according to Dhaka metropolitan Police, nearly 1.5 million rickshaw pullers are currently plying in the mega-city and more than 90 per cent of the rickshaw pullers have come to Dhaka straight from the villages (Begum and Sen, 2005). According to (Sohel, 2006) majority of them have no formal educational background, training and certificate and licences. Therefore since cycle-rickshaw pullers migrate to Dhaka city from rural parts of Bangladesh having no prior education, training and certificate, they tend to have weak knowledge about traffic signs and signals in order to commute along complex urban heterogeneous conditions.

Level of erratic and impatient behaviour (indicator 2)

Fig 17: Survey results for level of erratic and impatient behaviour



Level of erratic and impatient behaviour by cycle-rickshaw pullers were asked to 400 vehicle drivers about cycle-rickshaw pullers' queue-breaking tendency (I agree that rickshaws obeys its queue and doesn't take a u-turn to break its queue), wrong-way driving (I agree that rickshaws come in front of me from wrong direction which reduces the speed of my vehicle) and tendency to park at random places to pick and drop off passengers (I agree that rickshaws halt at random places to leave/take passengers which slows down my vehicle). For cycle-rickshaws queue-breaking tendency which was asked as a positive statement to avoid biased and unreliable answer showed that 46.88 % and 30.92 % chose Disagree and Strongly Disagree. For wrong-way driving and parking at random places tendency, which were negative statements 49.63 % and 42.17 % chose Strongly Agree and Agree and 72.07 % respondents chose Strongly Agree respectively. The results of the survey are corroborated with interview responses and secondary sources as explained below.

Table 9: Frequency distribution table for level of erratic and impatient behaviour (indicator 2)

Sub-variable	Indicator	Summary of interview responses	Frequency
Traffic-rule violation	Erratic and impatient behaviour	Many rickshaw pullers are impatient while driving their rickshaws. They stop in the middle of the roads, park at no parking zones and road junctions to pick up passengers.	5**
		Rickshaws often when they see a little bit empty space on the opposite road, they tend to move to that space to avoid congestion. Many times, the vehicles do not see the rickshaw coming towards it especially at night-time so the vehicle has to hard break in narrow and busy roads Rickshaws tend to do this at night-time when there is less traffic	2**

		and few traffic police	
		Most rickshaw pullers behave disobediently and are impatient when they want to avoid queues to pick up passengers	2**

**Total number of respondents=9

The results from the interviews show that 5/9 interview responses mentioned that many rickshaw pullers are impatient while driving their rickshaws. They stop in the middle of the roads, park at no parking zones and road junctions to pick up passengers and drives in the wrong way. Authors Al-Madani and Al-Janahi (2002) in their study said that prolonged traffic congestion can lead drivers to become frustrated and can lead to an extent of violating the lay down traffic rules. Furthermore, according to (Remi et al., 2009), bad attitude of drivers such a wrong way driving and picking of passengers have been identified as causes of traffic congestion. 2/9 interview responses mentioned that whenever rickshaws see an empty space on the opposite road, they tend to move to that space and position themselves to avoid congestion. The interviewee, (R:2) also added that many times the vehicles do not see the rickshaw coming towards it especially at night-time so the vehicle has to give hard brakes in narrow and busy roads which is dangerous and often causes accidents. Furthermore, rickshaws tend to do this at night-time when there is less traffic and few traffic police as corroborated by Ibadan (2020) that traffic law violations by vehicle drivers tend to be more in the evening peak period than the morning peak period as vehicle drivers take advantage of violating laws in the darkness. On the other hand, 2/9 interview responses behave disobediently and are impatient when they when want to avoid queues to pick up passengers. The interviewee, (R:7) mentioned that rickshaw pullers competitive tendency to reach their destination first influences them to violate traffic rules and more stringent laws must be implemented for them. Authors (Al-Madani and Al-Janahi, 2002) mentioned something similar in their study which showed that traffic violations are observed more for commercial drivers as they tend to break the traffic regulations when the traffic rate is high to reduce the unproductive time spent on roads which would have otherwise been used to pick up more passengers for achieving maximum profit. According to secondary sources (Tiwari, 2014) 96 % of cycle-rickshaws in Dhaka city do not own the rickshaws. They hire rickshaw on a monthly basis. Being stuck at prolonged traffic congestion for a rickshaw pullers could mean bearing extreme financial loss. For these reasons, erratic and impatient behaviour of rickshaw pullers to violate traffic rules could be because of the fact that they always want to meet their daily target profit and any hindrance against achieving the target amount imposes severe psychological, financial and physical stress which influences them to violate traffic rules in mega-city Dhaka.

''Most rickshaw pullers are uneducated and inexperienced, leading to a tendency among them to reach the destination first. I think we need more stringent laws for not trying for rickshaw pullers to be trained on the road, and be more aware of traffic laws in various ways.'' (R:7)

''Rickshaws do this all the time. Even if they get a little bit empty space, they always use that space even if it is on the wrong side of the road to avoid congestion. When I am driving at 50 km/hr, there is a very big chance that the rickshaw suddenly comes in front of me and I

cannot see it because of its size, so I have to give a hard break, which is the only way to go if it is a narrow road, but if it's a wider road then I slow my vehicle and swirl away as its difficult to reduce speed from a high speed to low speed, it often causes accidents as well. Once, from a space between a divider, a rickshaw came from the wrong side of the road and in front of me. These things happens all the time, everyday'' (R:3)

Before proceeding to the dependent variable, the reliability test of statistical results of this section was carried out for the independent variable. The reliability test included a total of 12 items of all the indicators of the sub-variables. The items showed an acceptable reliability with Cronbach's Alpha= 0.624.

4.4.5: Traffic congestion (Dependent variable)

This variable has two sub-variables named temporal-delay based congestion and spatial based congestion. The total number of indicators is 3. Each sub-variable was analysed separately where interview with survey results, interview responses and secondary sources wherever applicable in order to analyse the level of traffic congestion in the three study areas.

4.4.6 : Temporal-delay congestion (Sub-variable 1)

Two indicators were used to measure temporal delay congestion in this study for the three study areas namely, Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North), Shahbag Square to Science laboratory (Dhaka South), and Asad Gate to Mohammadpur Bus stop (Dhaka central). The indicators were termed as average travel time in peak hour and average time travelled in off-peak hour. The findings per indicator are presented below.

Average time travelled in peak hour (indicator 1)

Tale 10: Frequency distribution table of average travel time in peak hour

Sub-variables	Indicator	Summary of interview responses	Frequency
Temporal delay congestion	Average travel time in peak hour	Time travelled in peak hour is high than time travelled in non-peak hour	5**
		Travel time in evening peak period is higher than morning peak period	4**
		Both morning and evening travel time is high	2**

*Total number of respondents= 9***

In this study, travel time was measured using the data for the peak period. Findings from interviews were presented first followed with questionnaire findings. The interview responses show that time travelled in peak-period is higher than non-peak period according to 5 interview respondents. This finding will be corroborated with survey results and secondary sources as explained below. When asking respondents when travel time is high comparing morning and evening peak periods, 4/9 interviewees said that evening travel time is higher than morning because traffic congestion is higher in the evening than in the morning. 2/9 interview respondents even said that both morning and evening travel time is high. The

results from the survey show that evening Peak period travel time is higher than morning peak period travel time for the three study areas which will be further discussed below with statistical t-test and secondary sources. Furthermore, the results show peak period travel time is higher in the study road of Dhaka Central and Dhaka South than Dhaka North. This difference in travel time between the three study areas are also discussed below with secondary sources and academic literature review at the end of this section.

Fig 20: Travel time for Mohammadpur bus stop to Asad Gate bus stop(Dhaka Central)

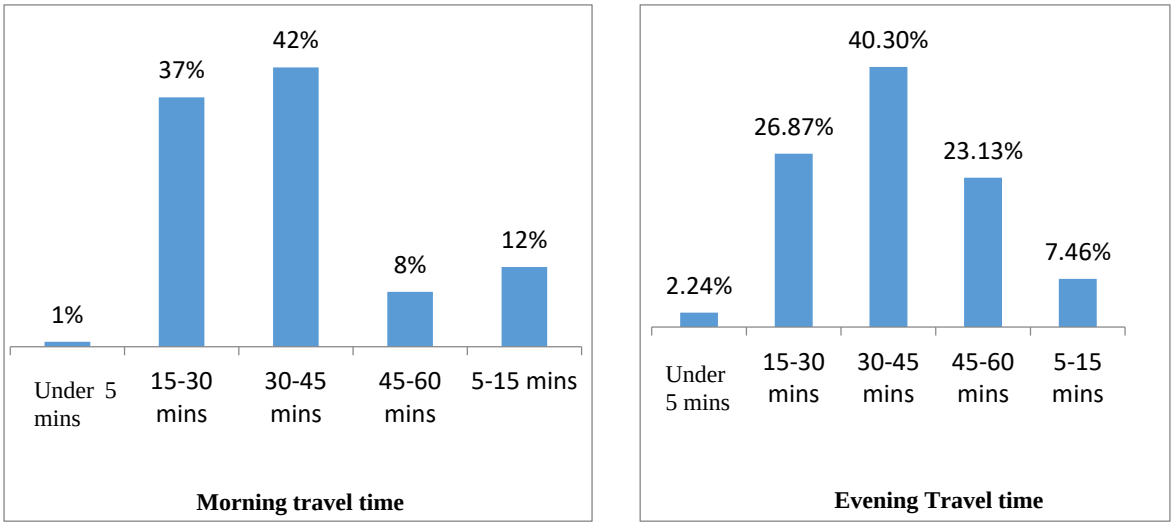


Fig 21: Travel time for Science lab to Shahbag Square (Dhaka South)

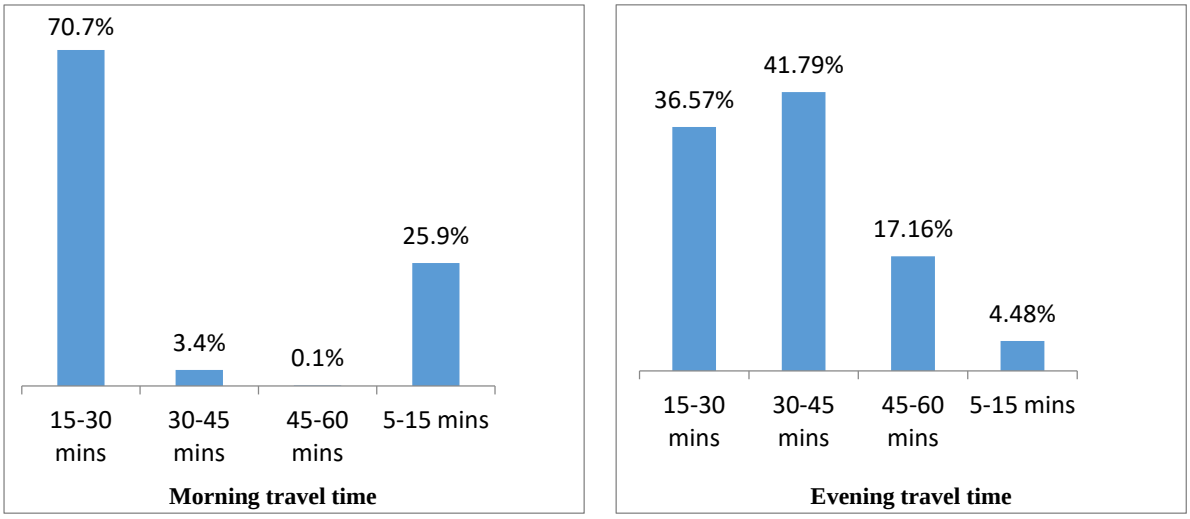
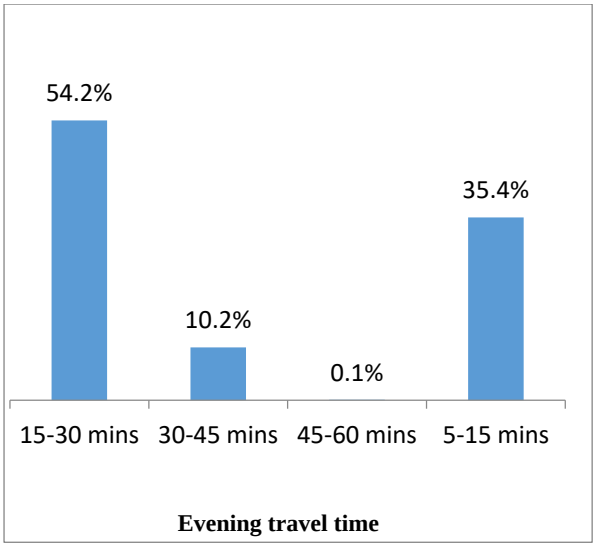
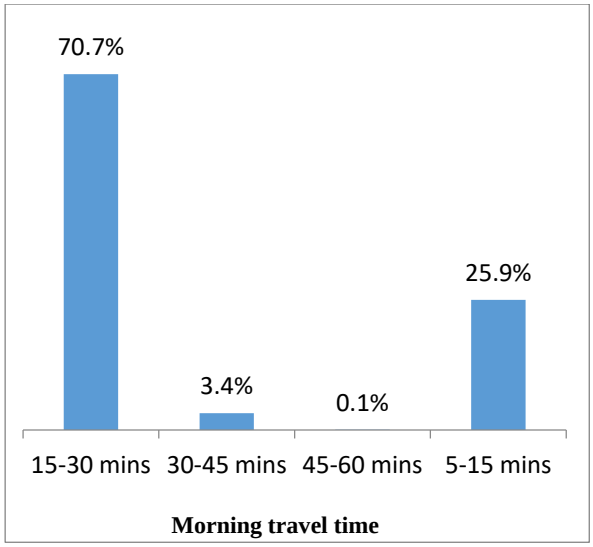


Fig 22: Travel time for Mascot Plaza to Uttara sector 11Wellfare Association (Dhaka North)





The average peak period travel time in each road for morning and evening times were calculated using the frequencies and mid-point of the travel time interval from figures 20, 21 and 22 above because the data collected for travel time are grouped. The table below summarizes the data for average peak period travel time in morning and average peak period travel time in evening for Dhaka North, Dhaka Central and Dhaka South.

Table 12: Summary of peak period travel times (morning and evening) for the three study areas

Study area	*Peak period travel time (morning)*	*Peak period travel time (evening)*
Uttara sector 11 to Mascot Plaza	20 mins	20 mins
Shahbag to science lab	29.58 mins	33.35 mins
Mohammadpur bus stop to Asad Gate bus stop	30 mins	34 mins

This section talks about the peak period travel time difference between morning and evening hours as seen from figure 22. Statistical t-test of paired mean between morning and evening peak period travel time data of the entire study area was conducted to support the results from the survey results and interviews. The results from the t-test are given below in figure 23.

Table 13: Statistical t-test of paired mean

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	morning travel time	3.23	401	.870	.043
	evening travel time	3.40	401	.939	.047

Even though respondents were asked about the travel time taken to cover the same length of road during the morning peak period and during the evening peak period, the statistical t-test of paired mean shows that the mean for evening peak period travel time is higher than the

morning peak period travel time from the above table. This can be explained by the delay on the roads during the evening time due to a number of factors. However, a study of literature review for cycle-rickshaws' traffic rule violation (sub-variable 3) as discussed in the earlier section, do corroborates these findings where according to (Ibadan, 2020) traffic law violations occur more in the evening peak period than the morning peak period as some vehicle drivers take advantage of darkness to disobey traffic laws hence causing chaos and disorder on the traffic flow. Moreover, as discussed in the earlier section, the interviewee, (R:5), when asked about cycle-rickshaws non-lane discipline movement by cycle-rickshaws (sub-variable 2), mentioned that cycle-rickshaws tend to swerve away abruptly during night-time, for which it gets very dangerous for the neighbouring vehicles because of the small size of cycle-rickshaw which is not fully visible during dark hours. Another traffic-rule violating behaviour by cycle-rickshaws was mentioned by interviewee (R:2) where the interviwee mentioned that cycle-rickshaws tend to move in the wrong-ways very often during the evening hours by taking advantage of the darkness when the traffic police is not watchful.
Statistical correlations were conducted between the independent variables and peak period travel times for both morning and evening periods to compare and contrast with the results which are explained in the section 4.4.7 later in the chapter below.

Average time travelled in off-peak hour (indicator 2)

Table 14: Frequency Distribution table for average time travelled in off-peak period

Sub-variables	Indicator	Summary of interview responses	Frequency
Temporal delay congestion	Average travel time in off-peak hour	Time travelled in off-peak period is shorter than peak-period.	3*

The second indicator for the sub-variable was average time travelled in off-peak period. The data was collected at midnight which is off-peak period under my study for the three areas which showed that travel time is 4 minutes, 4.5 minutes and 5 minutes for all the three study areas as three of the roads are similar in length being 1.6km, 1.4 km and 1.3 km respectively. The interview responses from the study areas sector pointed out that travel time in the off-peak period is lower compared to the peak-period. To corroborate this finding, secondary data source of google maps were used to find out off-peak period travel time. The results are presented in the table below.

Table 15: Off-peak period travel time data for the three study areas

Study area	***Off-peak period travel time (after midnight)***
Uttara sector 11 to Mascot Plaza (1.6 km)	*4 minutes*
Shahbag to Science lab (1.4 km)	4.5 minutes
Mohammadput bus stop to Asad Gate bus	5 minutes

stop(1.3 km)	

Source: Google maps

It can also be interpreted that since travel time is lower in peak period than off-peak period, travel speed is lower in peak-period than off-peak period as explained in section 4.4.6. To close this section, it is evident that the travel time in off-peak period is lower than travel time in peak period.

4.4.7: Sub-variable 2 (Spatial based congestion)

This sub-variable has one indicator which is level of service. To determine the level of service average vehicle speed was used to determine which level of service belongs to each road using distance and travel time measures presented in the sections above. The level of service ranges from A to F based on different factors. Results from survey data for travel time along with different academic literatures were used to categorize the level of service of each road under the study. The findings from the indicator are presented below.

Level of service (indicator-1)

Level of service can be used to measure the magnitude and the volume of traffic flow of selected roads by comparing peak and off-peak period speed. Level of service of a road ranges from A to F based on various factors. To identify which level of service belongs to each of the study areas, average vehicular speed are needed to be found out. The average vehicular speed of each road is calculated by the distance of each road and average travel time taken in peak and off-peak periods to cover that distance. The table below summarizes the average vehicular speed of morning and evening peak period for the study roads.

Table 16: Average vehicular speed for peak period and off-peak period for the three study areas

Road	distance	Travel time in off-peak period (midnight)	**Speed in off-peak period (midnight)**	Travel time in peak period (morning)	**Speed in peak period (morning)**	Travel time in peak period(evening)	**Speed in peak period (evening)**
Uttara sector 11 to Mascot Plaza (Dhaka North)	1.6 km	4 mins	**26 km/h**	20 mins	**4.8 km/h**	20 mins	**4.8 km/h**
Shahbag to Science lab(Dhaka South)	1.4 km	4.5 mins	**18.66 km/h**	29.58 mins	**2.8 km/h**	33.35 mins	**2.54 km/h**

Mohammadpur bus stop to Asad Gate bus stop(Dhaka North)	1.3 km	5 mins	**16.25 km/h**	30 mins	**2.6 km/h**	34 mins	**2.32 km/h**

To compare peak period and off-peak period travel time and speed, speed reduction index was used. Speed reduction index, SRI is the ratio of the relative speed change between congested and free-flow conditions, as shown in the equation below. The SRI ratio is multiplied by 10 to keep the values of SRI in the range of 0 to 10. Congestion occurs when the index value exceeds above 4. Values less than 4 indicate a non-congested condition (Afrin and Yodo, 2020)

SRI=(1-Vac/Vff) X 10, where SRI denotes the speed reduction index, Vac indicates the actual travel speed, and Vff means the free-flow speed. The free-flow speed generally refers to the average speed of the off-peak period. Based on the above formula, and the data from table 16, SRI of Uttara Mascot Plaza to Uttara Sector 11 Wellfare Association (Dhaka North) road is 8.2, 8.2 , Mohammadpur bus stop to Asad Gate bus stop (Dhaka central) (8.4), 8.6 and Shahbag to Science lab (Dhaka South) is 8.5, 8.7. The results show that all the roads have SRI which is higher than 5 which means that the roads are congested.

Table 17 : Level of service for different speed limits

Level of service	**Average vehicle speed**	**Quality of road**
A	>40 km/h	Free flow
B	>32-40 km/h	Stable vehicle flow
C	>24-32 km/h	Stable vehicle flow
D	>16-24 km/h	Less stable vehicle flow
E	>8-16 km/h	Unstable vehicle flow
F	≤8 km/h	Forced vehicle flow

Source: (Deshpande, et al., 2010)

The above table shows the different categories of levels of service for speed limit of 40km/hr to 8 km/hr. 40 km/hr was used as the maximum vehicle speed limit as in Dhaka city the maximum average vehicular speed limit is 40km/hr on urban roads. Based on this ratio, the level of service for each road was classified and described below.

Level of service for Uttara Mascot Plaza to Uttara Sector 11 Wellfare association (Dhaka North)

Based on the speed achieved by vehicles in both morning and evening peak period which is the road is classified under level F which means that there is forced flow of vehicles during peak periods.

Level of service for Mohammadpur bus stop to Asad Gate (Dhaka Central):

Based on the speed achieved by vehicles in both morning and evening peak period which is the road is classified under level F which means that there is forced flow of vehicles during peak periods.

Level of service for Shahbag to Science lab (Dhaka South):

Based on the speed achieved by vehicles in both morning and evening peak period which is the road is classified under level F which means that there is forced flow of vehicles during peak periods.

For further statistical analysis, the reliability analysis conducted on questionnaire data of Traffic congestion indicators shows a good reliability of Cronbach $\alpha = 0.869$ for The indicators tested included morning peak period travel time and evening peak period travel time for the entire study area which indicated that the indicators were measured in a consistent way and thus was reliable.

4.4.8: Statistical relationships

This section presents the Spearman's correlation test between dependent variable and independent variables of the three study areas separately. Spearman correlation test is used because the dependent variable data is ordinal. The indicators used for dependent variable is morning and evening travel time along with the 12 items of independent variable used in the questionnaire. The table below shows the correlation results for Dhaka North, Dhaka Central and Dhaka South between travel time as the dependent variable and independent variables were statistically significant among others as presented in the table 18 and 19. Only the study area of Dhaka South and Dhaka central showed significant values which are presented in the table below and explained further. The correlation results for morning and evening travel time also showed significant differences in some aspects which are presented as well. However, correlation results from Dhaka North did not show any statistical significance which are also explained below.

Table 18 : Spearman's correlation results for Mohammadpur bus stop to Asad Gate bus stop and Shahbag to Science (Dhaka Central)

	Travel time (morning)	Travel time (evening)
Level of overtaking	0.329	0.221
Level of travelling abreast	0.329	0.221
Level of tailgating	0.406	0.336

Level of swerving	0.221	0.186
Disobeying 'school ahead' sign	0.422	0.226
Disobeying pedestrian crossing sign	0.285	0.278
Level of wrong-way driving	0.393	0.301
Level of illegal parking	0.221	0.298

*Correlation is significant at 0.005 level(2-tailed)

Fig 19 : Spearman's correlation results for Shahbag to Science (Dhaka South)

	Travel time (morning)	Travel time (evening)
Level of overtaking	0.233	0.302
Level of travelling abreast	0.329	0.233
Level of tailgating	0.241	0.308
Level of swerving	0.221	0.191
Disobeying 'school ahead' sign	0.422	0.223
Disobeying pedestrian crossing sign	0.285	0.278
Level of wrong-way driving	0.393	0.301
Level of illegal parking	0.421	0.461

*Correlation is significant at 0.005 level(2-tailed

For Asad Gate to Mohammadpur bus stop (Dhaka Central), the spearman correlation results show that there is a positive significant correlation between morning and evening travel time (dependent variables) and most of the independent variables: level of overtaking, level of travelling abreast, level of tailgating, level of swerving, level of disobeying school ahead sign, level of disobeying pedestrian crossing sign, level of wrong-way driving and level of illegal parking by cycle-rickshaws. For Shahbag to Science lab, the spearman correlation showed positive correlation for level of swerving with morning travel time and level of swerving, level of disobeying signals from traffic police and level of disobeying queues with evening travel time. The positive correlation means that as more number of people agreed on the above independent variables, movements of cycle-rickshaws, the more number of people chose a higher option of travel time to commute from Mohammadpur Bus stop to Asad Gate and Shahbag to Science lab. In other words, vehicle drivers increased travel time on the road correlates with their increased perception of cycle rickshaws level of swerving, tailgating, overtaking, illegal parking etc. On the other hands, SPPS did not show any statistical significant relationship between travel time data of Dhaka North and its independent variables. This could be because travel time in North is much lower than South and Central. So, even though high number of respondents agreed on the movement of cycle-rickshaws as seen in the mean value (simple average of mean values for all the sub-variables) for Dhaka North in the figure 20 below that influence traffic congestion, this did not influence increased travel time in Dhaka North, therefore less congestion.

Table 20: Mean of Variables for study areas

Study area road	Sub-variable-1	Sub-variable-2	Sub-variable 3	No of population	Movement of cycle-rickshaw
Dhaka North	4.22	4.32	4.66	133	4.4
Dhaka Central	4.31	4.33	4.71	133	4.45
Dhaka South	4.45	4.47	4.77	133	4.46

The reason for this could be because of Dhaka North's better physical conditions like wider roads and better traffic management systems like stricter law enforcement for which traffic congestion by cycle-rickshaw movement is minimized.

Another reason why travel time data is lower in Dhaka North than Dhaka South and Central is because of the differences between the geographical and socioeconomic characteristics, land use patterns and connectivity of the three study areas. According to a report titled, 'Growth and Development of Dhaka North 1971-2011' by Ahmed (2013), the socioeconomic profile of inhabitants in Uttara region (Dhaka North) mostly lies in the middle to higher income groups. Uttara is at the furthest end of the Greater Dhaka administrative border which was planned initially as a satellite town in the year 1965 by Dhaka Improvement Trust (DIT) to accommodate middle income groups. However, due to inappropriate allocation procedure and rapid increase of land price, Uttara region has given rise to many high class residential areas (Kabir and Parolin, 2012). On the other hand, the inhabitants of the study areas of Dhaka central and Dhaka South belongs to a varied group of socioeconomic characteristics ranging from lower, middle, upper middle to higher income groups. In addition to that, the geographical locations of Asad Gate bus stop to Mohammadpur bus stop and Shahbag to Science lab allows commuters from different parts of Dhaka city to access these roads unlike Uttara road which is on the furthest end restricting to the movement of the northern most part of Dhaka exclusively which mostly consists of middle to higher income groups of people. Research says that there is a positive correlation between income levels and vehicle ownership (Jose, 1989). Therefore as Uttara neighbourhood has inhabitants with higher income levels, most inhabitants own private cars and choose to commute with motorised vehicles rather than non-motorised vehicles unlike Dhaka central and Dhaka South where income levels are varied resulting in a varied mix of motorised and non-motorised vehicles used by the inhabitants for making trips. Therefore, it can be interpreted that even though inhabitants of Dhaka North highly agree on cycle-rickshaw's leader vehicle following (sub-variable 1), non-lane discipline (sub-variable 2) and traffic-rule violating (sub-variable 3) movement, in general there are fewer number of cycle-rickshaws commuting on Dhaka North than South and Central because of its less demand from middle-higher income groups, therefore fewer interactions between motorised and non-motorised vehicles. Therefore, it can be concluded that heterogeneousity of a road varies indirectly with the socio-economic

characteristics of a neighbourhood which ultimately influences the levels of congestion on its roads. The lower the heterogenousity of vehicles the lesser the interactions between motorised and non-motorised vehicles (cycle-rickshaws) resulting in lower levels of traffic congestion.

Chapter 5: Conclusion

5.1: Introduction

This chapter seeks to present the main findings discussed in chapter-4. The findings are presented in line with answering the sub-questions and the main research question of the study based on the findings from the surveys, interviews and secondary sources linking with literature reviewed. The chapter focuses in establishing the relationship between the independent and dependent variable by answering the research questions. The chapter ends with the presentation of practical recommendations, as well as recommendations for further and future studies.

5.2: Main findings of the research

Sub-question 1: What is the current state/condition of traffic congestion in Dhaka North, Dhaka Central and Dhaka South roads of mega-city Dhaka?

To answer the first sub-research question, temporal delay based congestion and spatial based congestion have been used as sub-variables. Under the two sub-variables, average travel time in peak period, average travel time in off-peak period and level of service have been used as indicators to estimate the level of traffic congestion for the study areas. Travel time data was used to measure traffic congestion as it is reported that delay in productive hours is an indication of traffic congestion (Rao, 2012). By comparing the travel time data for peak period and off-peak period, speed reduction index (SRI) was used to identify the relative speed change between congested and free-slow conditions in the three study areas. In urban traffic roads, congestion is defined as a function of a reduction in speeds which is a direct cause of increased travel time (Rao, 2016). On the other hand, levels of service (LOS) was used to analyze traffic congestion as a qualitative measurement that categorized the three study areas into categories of A to F that best reflect the quality of motor vehicle traffic service on the road.

To answer this question, data from both primary and secondary sources were used. Primary sources included questionnaires and interviews whereas secondary sources included academic literature and google maps. Analysing data from all the sources revealed that the three roads named Uttara Mascot Paza to Sector 11 Wellfare association (Dhaka North), Shahbag to Science lab (Dhaka South) and Mohammadur bus stop to Asad Gate (Dhaka central) are all congested with Dhaka Central and Dhaka South being more congested than Dhaka North. The findings are explained below.

At first, peak-period travel time data for both morning and evening time were collected from the surveys of 400 vehicle drivers who drive on the three study areas. These data were used to find the morning and evening peak-period average vehicular speed of each road. A total of 9 key informants (3 traffic police, 2 vehicle drivers, 2 rickshaw passengers and 2 pedestrians)

were interviewed about the peak period travel times as well. To find the off-peak period travel time, google maps was used as a secondary source which showed off-peak period travel time for the three study areas.

Based on both questionnaire, interview responses, and secondary sources it was revealed that peak period travel time is higher than off-peak period travel time and peak period travel time in evening is higher than peak period travel time in morning. Using the questionnaire data of 400 vehicle drivers, statistical t-test of paired mean was conducted which showed that the mean for the evening travel time is higher than the mean for morning travel time, corroborating with the results from interview responses where most interviews mentioned about this. Using the data from questionnaires, interviews and secondary sources, average speed of each road in morning and evening peak and off-peak period was calculated. This showed a difference in speed between peak period and off-peak period and morning peak-period and evening peak period. The difference in speeds were used to calculate the speed reduction index for each road. Speed reduction index, is the ratio of the relative speed change between congested and free-flow conditions. The speed reduction index revealed that SRI ratio for both Dhaka Central road and Dhaka South road is 7.5 whereas SRI index for Dhaka North is 5.7 implying that three of the study area roads are congested but Dhaka Central and Dhaka South has higher levels of congestion than Dhaka North road. Secondly, using the speed data, levels of service of each road was found where all the three roads, Dhaka North, Dhaka Central and Dhaka South were classified under the lowest level of classification, category F, which means that there is a forced flow of vehicles on all the three roads.

To conclude we can say that levels of service represented the quality of traffic flow on the three roads, signifying that the three roads have forced flow of vehicle which means very high levels of congestion, and SRI index showed that between the three roads, higher levels of congestion exist in Dhaka Central and Dhaka South roads than Dhaka North road due to the high difference between the SRI ratio of Dhaka Central and South and Dhaka North as mentioned in the section 4.4.7.

Sub-question-2: How does the movement amongst vehicle types by cycle rickshaws influence traffic congestion in Dhaka North, Dhaka Central and Dhaka South of mega-city Dhaka?

Movement amongst vehicle types in this study were discussed in terms of the two indicators following *leader vehicle of different speeds and following leader vehicle of different sizes.* The two indicators were analysed based on the findings from the questionnaires, interviews, statistical data linking with academic sources.

For the surveys, the two indicators were analysed using the same dataset where 400 vehicle drivers of *different speeds and sizes* were asked about cycle-rickshaws tendency to tailgate, travel abreast and overtake their vehicles. Tailgating, travelling abreast and overtaking are three different types of movement a cycle-rickshaw makes in order to follow a leader vehicle of different speed and size. The same dataset for the survey responses of both the indicators were used as the survey respondents consisted of a mix of 400 vehicles of varied mechanical

characteristics of which vehicle drivers of both different speeds and sizes of vehicles were included. However, the two indicators were analysed separately with interviews from 9 key informants in an attempt to get a more in-depth understanding of the subject matter.

From the survey responses of following leader vehicle of different speeds, a very high agreement for all the three types of movements (tailgating, overtaking and travelling abreast) were found from the survey respondents. The results are justified by the observations of authors Budhakar and Maurya (2017) and Sarlas and Papathanasopoulou (2013) who mentioned in their studies that the most common characteristic of a heterogeneous traffic flow is that a single vehicle follows multiple leader vehicles of different speeds and each manoeuvre varies significantly from one another. It was revealed that majority of the interview responses corroborated the survey results and agreed about cycle-rickshaws' tendency of following *leader vehicle of different speeds*. Interviewees mentioned that cycle-rickshaws tendency of following a fast moving leader vehicle when the traffic is stopped and positioning itself in front it, cycle-rickshaws' tendency of stopping in front of motorised vehicles to pick up/drop off passengers at random places, the inability of cycle-rickshaw to accelerate back once they have stopped for picking up/dropping off passengers and the inability of other fast moving vehicles to overtake a much slower moving vehicle like cycle-rickshaw to avoid accidents all suggested that the relatively pace of cycle-rickshaws act as an obstacle for other fast pace motorised leader vehicles to maintain their average speed in heterogeneous traffic streams. Academic literature also corroborated the above findings where authors Khan and Maini (1999) and Sarlas, et al., (2013) mentioned that because of the complexity of heterogeneous traffic stream, non-motorised vehicles like cycle-rickshaws get numerous opportunities to follow a leader vehicle even if significant difference of speed exist between them which causes disruptions for fast moving vehicles.

In conclusion, the findings above collected from various sources all suggest that motorised vehicles of higher speeds have to reduce their average speeds when followed by cycle-rickshaws in various scenarios under heterogeneous traffic conditions.

Similarly, for the indicator *following leader vehicle of different sizes*, as mentioned above survey respondents showed very high agreement for the tendency of cycle-rickshaws to follow a larger sized leader vehicle. The survey results were corroborated with interview respondents where majority of the respondents mentioned cycle-rickshaws tendency of following larger sized vehicles and positioning itself between available gaps of vehicles when the traffic is stopped, and the inability of large sized motorised vehicles to overtake the cycle-rickshaws as the large vehicle requires more manoeuvring space, all suggest that large sized motorised vehicles have to compromise their speed when being followed by cycle-rickshaws. The findings from the survey and interviews are corroborated by authors Madhu, Sivanandan and Srinivasan (2020), (Sarlas, Papathanasopoulou and Antoniou, 2013) and (Munigety and Mathew, 2016) who mentioned that in heterogeneous conditions, small vehicles can place themselves anywhere in the traffic stream depending on availability of gaps between vehicles, however large sized vehicles behind the cycle-rickshaw find difficulties in overtaking it as it occupies more space which influences its turning capabilities. Therefore, the vehicles tend to remain at rest compromising its average vehicular speed.

In conclusion, the findings above collected from various sources all suggest that motorised vehicles of larger sizes have to reduce their average speeds when followed by cycle-rickshaws.

As explained in sub-question 1, the level of traffic congestion in this study for the three study areas are determined by the Speed reduction index and Level of Service. Speed reduction index uses peak period and off-peak vehicular speed and level of service uses peak period speed limit with the average speed limit allowed during free flowing traffic in Dhaka city. Traffic congestion is defined as a function of reduction of speeds which is a direct cause of increased travel time (Rao, 2016). Therefore, reduction of average vehicular speed on the traffic flow concluded that traffic congestion exists on Dhaka North, Dhaka Central and Dhaka South roads. The findings collected from the above indicators all suggest that due to the movement of cycle-rickshaws average vehicular speed of the motorised vehicles decrease.

Statistical correlations were conducted between travel time(dependent) data and the indicators of movement amongst vehicle types (independent) of the three study areas which showed significant positive correlations for Dhaka Central and South but not North. The difference of correlations in Dhaka North than Dhaka South and Central is justified with the higher peak period travel time of Dhaka Central and Dhaka South than Dhaka North. This can be interpreted by saying that Dhaka North has better road conditions and traffic management systems than the other two which minimizes the effects of congestion influenced by cycle-rickshaws movement amongst vehicle types. Furthermore, secondary sources reveal that the socio-economic characteristics of Dhaka North is higher than Dhaka Central and Dhaka South which means that the inhabitants of Dhaka North mostly own motorised vehicles or private cars and the demand of cycle-rickshaw is less. Research says vehicle occupancy is highly correlated with income levels. Therefore even though respondents highly agreed about cycle-rickshaws tendency to follow leader vehicles, in reality in Dhaka North there are fewer frequent interactions of motorised and non-motorised vehicles and fewer opportunities for cycle-rickshaws to move among vehicle types, hence less congestion.

Therefore, to sum up the above findings, the researcher has concluded that the movement amongst vehicle types by cycle-rickshaws has influenced traffic congestion in Dhaka North, Dhaka Central and Dhaka South by reducing the average vehicular speed of the traffic on the above mentioned roads with Dhaka Central and Dhaka South being more influenced by cycle-rickshaws movement amongst vehicle types.

Sub-question 3: How does non-lane discipline movement by cycle-rickshaws influence traffic congestion in Dhaka North, Dhaka Central and Dhaka South in mega-city Dhaka?

Answer: Non-lane discipline movement in this study was discussed in terms of two types of movement by cycle-rickshaws namely swerving and lane-splitting. Swerving is defined as a tendency of the cycle-rickshaw's abrupt changing of direction away from its lane and lane-splitting is defined as the tendency of cycle-rickshaws movement between lanes of rows of

slow moving or stopped vehicles to bypass traffic congestion. Findings from swerving and lane-splitting collected from surveys, interviews, statistical data and secondary sources are discussed below.

At first, the extent of agreement or disagreement towards level of swerving by cycle-rickshaws were analysed by surveying 400 vehicle drivers who drive on Dhaka North, Dhaka central and Dhaka South roads. The survey results depicted very high agreement for the level of swerving by cycle-rickshaws for the entire study area. The survey result was corroborated by author Munigety and Mathew (2016) who mentioned that in heterogeneous conditions vehicle drivers exhibit peculiar movement patterns like swerving due to possessing weak lane discipline.

The results from the surveys were corroborated with majority of the interviews where 9 key informants revealed that due to the abrupt swerving of cycle-rickshaws, vehicles coming from behind the cycle-rickshaw has to immediately reduce their speeds drastically, give hard brakes or change directions to avoid possible collisions Vehicle drivers do not get enough time to give indicators to other vehicle drivers that are behind. Additionally, it was also revealed that, as a reaction to this abrupt swerving, even when vehicle drivers manage to reduce their speed in due time, they find difficulties in accelerating back to their original speeds. The findings above were again corroborated with secondary sources where Khan and Maini (1999) and Munigety and Mathew (2016) mentioned that rickshaw pullers make abrupt decisions to change their directions and this change on maneuverability in heterogenous conditions, not only creates disruption for the surrounding vehicles but also to the ones that are coming from behind resulting in traffic congestions on urban traffic systems.

Therefore, to sum up from the above findings collected from surveys, interviews, and academic literature motorised vehicles have to compromise their as a reaction to cycle-rickshaws abrupt tendency of swerving away from its lane.

Non-lane discipline in this study was defined by lane-splitting where 400 vehicle drivers on the three study roads were surveyed. The results showed very high agreement for the level of lane-splitting of cycle-rickshaws. The high agreement of cycle-rickshaws level of lane-splitting by vehicle drivers revealed from survey responses were corroborated with secondary sources, where authors (Agarwal and Lammel, 2015) and (Parsuvanathan, 2015) mentioned that in heterogenous congested roads in developing countries, smaller vehicles do not stop at the end of the queues and instead take advantage of their sizes and manoeuvre easily between gaps to avoid being stopped at traffic for long hours. The above findings from surveys were further corroborated by 9 interview responses. Interviewees mentioned that as cycle-rickshaws tend to take position in gaps between neighbouring vehicles to move in-between them to avoid congestion, it also influences other motorised vehicles to move away from their lane as well which gives rise to chaotic traffic flow resulting in a reduction of vehicular speed of the traffic. Additionally, cycle-rickshaws chaotic and random placement on urban traffic streams due to its lane-splitting, acts as a hindrance for the motorised vehicles to accelerate and cross the intersections in due time resulting in formations of long queues of vehicles who have failed to cross the intersections on time. This was corroborated by Madhu, Sivanandan and Srinivasan (2020) who mentioned that in mixed traffic streams, two and three-wheelers

use their opportunity of flexible maneovering and size to move through the gaps available between the vehicles leading to overall chaotic vehicular movement patterns and adverse traffic congestion and accidents. Furthermore lane-splitting by cycle-rickshaws also played a role in causing road traffic accidents as mentioned by interviewees because of the rickshaw pullers underestimation of the space required to move in-between vehicles which very often damages the body of the vehicles when the rickshaw is trying to move in between the gaps.

The above findings collected from the above sources suggest that motorised vehicles reduce their speed as a consequence of cycle-rickshaws tendency of lane-splitting which influences traffic congestion on the three study areas.

As explained in sub-question 1, the level of traffic congestion in this study for the three study areas are determined by the Speed reduction index and Level of Service. Traffic congestion is defined as a function of reduction of speeds which is a direct cause of increased travel time (Rao, 2016). Therefore, reduction of average vehicular speed on the traffic flow concluded that traffic congestion exists on Dhaka North, Dhaka Central and Dhaka South roads. The findings collected from the above discussions all suggest that due to non-lane discipline movement of cycle-rickshaws, average vehicular speed of the motorised vehicles decrease. Statistical correlations were conducted between travel time(dependent) data and the indicators of movement amongst vehicle types (independent) of the three study areas which showed significant positive correlations for Dhaka Central and South but not North. Even though survey results, interviews and google maps reveal that traffic congestion exist in all the three study areas (Central, South and North). On the other hand, survey results, interviews and secondary sources also showed high agreement for the independent variables (swerving and lane-splitting) in the three study areas including North.

Statistical correlations were conducted between travel time(dependent) data and the indicators of movement amongst vehicle types (independent) of the three study areas which showed significant positive correlations for Dhaka Central and South but not North. Even though survey results, interviews and google maps reveal that traffic congestion exist in all the three study areas (Central, South and North). On the other hand, survey results, interviews and secondary sources also showed high agreement for the independent variables (swerving and lane-splitting) in the three study areas including North. The difference of correlations in Dhaka North than Dhaka South and Central is justified with the higher peak period travel time of Dhaka Central and Dhaka South than Dhaka North. This is because Dhaka North could have better road conditions and traffic management systems than the other two which minimized the influence of cycle-rickshaws movement amongst vehicle types on traffic congestion. This finding was further corroborated with the secondary sources that the socio-economic characteristics of Dhaka North is higher than Dhaka Central and Dhaka South which means that inhabitants of Dhaka North mostly own motorised vehicles or private cars. Research says vehicle occupancy is highly correlated with income levels. Therefore even though respondents highly agreed about cycle-rickshaws tendency to follow leader vehicles, in reality the demand of cycle-rickshaw is much less in Dhaka North than South and Central influencing fewer frequent interactions of motorised and non-motorised vehicles and fewer swerving and lane-splitting tendencies by cycle-rickshaws in North than Central and South.

Therefore, to sum up the above findings, the researcher has concluded that non-lane discipline movement by cycle-rickshaws has influenced traffic congestion in Dhaka North, Dhaka Central and Dhaka South by reducing the average vehicular speed of the traffic on the three study areas with Dhaka Central and Dhaka South being more influenced by cycle-rickshaws' non-lane discipline.

Sub-question 4: How does traffic rule violation by cycle-rickshaw movement influence traffic congestion in Dhaka North, Dhaka Central and Dhaka South of mega-city Dhaka?

Traffic rule violation by cycle-rickshaws were defined by the two indicators namely level of obeying traffic signs and symbols and level of erratic and impatient behaviour. The findings for the two indicators collected from survey responses, interview data, statistical relationships and secondary sources are discussed below.

To identify the level of *obeying traffic signs and signals* by cycle-rickshaws, 400 vehicle drivers were surveyed about the level of obeying of three traffic signs. The three traffic signs were school-ahead sign, pedestrian crossing sign and no-rickshaw entry sign. The survey responses showed strong disagreement for cycle-rickshaws level of obeying traffic signs. The survey responses were corroborated with interview results were interviewees mentioned that even though cycle-rickshaws are prohibited to enter from adjacent roads, they often see rickshaws coming from adjacent roads which causes disruptions of traffic flow especially if the rickshaw comes in front of a motorised vehicle while it is entering. Furthermore, interviewees mentioned that majority of cycle-rickshaw pullers according to his experience, do not understand the traffic signs and signals by the police and for this reason they are constantly disobeying them. These findings were corroborated in a report by Dhaka Metropolitan Police who claimed that among 1.5 million rickshaw pullers plying in the mega-city, more than 90 percent of them directly come from the rural parts of Bangladesh. Academic literature review also supported this finding as authors (Begum and Sen, 2005)and (Sohel, 2006) mentioned that since cycle-rickshaw pullers migrate to Dhaka city from rural parts of Bangladesh, they lack formal traffic education, training, certificates or licenses prior to arriving in Dhaka city and possess weak knowledge of traffic signs and signals which leads them to violate traffic laws in motion. Additionally, the second part of the indicator, level of obeying traffic signals were also surveyed to 400 vehicle drivers. The survey responses revealed that 30.6 % chose Disagree whereas 35.91 % chose Agree. The difference in opinion for level of obeying traffic signals exist due to the fact that traffic signals are given by the traffic police in Dhaka city and 35.91 % respondents who chose Agree for cycle-rickshaws obeying traffic signals believe that the fear of being fined by the police acts as a motivation for rickshaw pullers to obey traffic signals. However when asked to 3 traffic police in the three study areas about cycle-rickshaws tendency of obeying traffic signals, they claimed that rickshaw pullers do not understand the signals and they face difficulties in handling them every day. Additionally, interviewees mentioned that rickshaw pullers try to cross the signals even when the light is not green especially when there is no traffic police patrolling or at night when they are not watchful and because of this they are constantly being fined. This

finding is corroborated with the literature that according to (Ibadan, 2020) traffic law violations by vehicle drivers tend to be more in the evening peak period than the morning peak period as vehicle drivers take advantage of violating laws in the darkness. Statistical t-test of paired mean between morning and evening peak period travel time of the entire study area was conducted which showed a higher mean for evening peak period travel time than morning. This could be because of the above mentioned reasons that traffic-rule violation by cycle-rickshaws are more in the evening time than morning time which results in delays on the road resulting to increased travel time for the vehicle drivers.

To analyse indicator 2, *level of erratic and impatient behaviour by cycle-rickshaws*, 400 vehicle drivers were surveyed about cycle-rickshaws queue-breaking tendency, wrong-way driving and illegal parking. The results showed strong agreement for the above mentioned indicators. The above findings from interviews and survey responses were corroborated with secondary sources where authors (Remi et al., 2009) mentioned that bad attitude of drivers such as wrong way driving and picking of passengers has been identified as causes of traffic congestion.

The survey responses were corroborated with interviews where respondents mentioned that rickshaws stop in the roads where they are not supposed to, park at no-parking zones and road junctions and drive in the wrong-ways. This causes the motorised vehicles on the road to reduce their speed drastically or do hard brakes. These behaviours get even more dangerous at night in narrow and busy roads when the vehicle driver cannot see the cycle-rickshaw coming towards it from wrong directions which also causes accidents. The interviewees further mentioned that rickshaw pullers tendency to reach the destination first influences them to violate traffic rules and more stringent laws must be implemented for them. Authors (Al-Madani and Al-Janahi, 2002) mentioned that traffic violations are observed more for commercial drivers as they tend to break the traffic regulations when the traffic rate is high to reduce the unproductive time spent on roads which would have otherwise been used to pick up more passengers for achieving maximum profit. Therefore it is concluded that cycle-rickshaws erratic and impatient behaviour is because of the fact that want to meet their daily target profit and any hindrance against achieving the target amount imposes severe psychological, financial and physical stress which influences them to violate traffic rules in mega-city Dhaka.

Statistical correlations were conducted between travel time(dependent) data and the independent variables of the three study areas which showed significant positive correlations for Dhaka Central and South but not North. On the other hand, survey results, interviews and secondary sources also showed high agreement for the independent variables in the three study areas including North. The difference of correlations in Dhaka North than Dhaka South and Central is justified with the higher peak period travel time of Dhaka Central and Dhaka South than Dhaka North. This could be because of Dhaka North having better road conditions, traffic management systems and less number of cycle-rickshaws moving on Dhaka North than the other two which minimized the influence on traffic congestion. This finding was further corroborated with the secondary sources that the socio-economic characteristics of Dhaka North is higher than Dhaka Central and Dhaka South which means

that inhabitants of Dhaka North mostly own motorised vehicles or private cars. Research says vehicle occupancy is highly correlated with income levels. Therefore even though respondents highly agreed about cycle-rickshaws level traffic-rule violating behaviour by cycle-rickshaws, in reality there are fewer frequent interactions of motorised vehicles and cycle-rickshaws and fewer traffic-rule violating behaviour that influences the vehicular speed of motorised vehicles Dhaka North than Central and South.

Therefore, to sum up the above findings, the researcher has concluded that traffic-rule violations by cycle-rickshaws has influenced traffic congestion in Dhaka North, Dhaka Central and Dhaka South by reducing the average vehicular speed of the traffic on the three study areas with Dhaka Central and Dhaka South being more influenced by cycle-rickshaws' traffic-rule violation.

Main RQ: How does the movement of cycle-rickshaws influence traffic congestion in area Dhaka North, Dhaka Central and Dhaka South of mega-city Dhaka?

The above section answers each sub-research question where how movement amongst vehicle types, non-lane discipline and traffic-rule violation influenced traffic congestion. This section discusses about how the 'movement of cycle-rickshaws' as the independent variable influenced traffic congestion as the dependent variable.

As discussed above, cycle-rickshaws movement amongst vehicle types have influenced traffic congestion by reducing the average vehicular speed of the traffic. The findings collected from the surveys, interviews and secondary sources all suggested that as cycle-rickshaws move amongst vehicle types of different speeds and sizes, they tend to influence the movement of other motorised vehicles of different speeds and sizes. The findings conclude that when a cycle-rickshaw follows a leader vehicle which has a faster speed, it tends to position itself in front of it when the traffic is stopped eventually being a hindrance for fast moving motorised vehicles that are behind it when the traffic starts to move and the vehicle needs to accelerate. Likewise, when a cycle-rickshaw follows a leader vehicle of larger size, it tends to position itself within available gaps of large sized vehicles. However the large sized vehicle cannot overtake the cycle-rickshaw as it requires more space for manoeuvring hence its speed is compromise. Because of the above mentioned reasons the cycle-rickshaws movement amongst vehicle types influences traffic congestion by reducing the average vehicular speed. The findings collected were corroborated with authors Madhu, Sivanandan, et al., (2020), Sarlas, Papathanasopoulou, et al., (2013), Munigety and Mathew (2016) and Khan and Maini (1999). Furthermore, cycle-rickshaws non-lane discipline movement also influence traffic congestion by reducing the average vehicular speed of the traffic. The findings collected all conclude that because of non-lane discipline movement of cycle-rickshaws, they tend to swerve away from their lane and lane-split between stationary vehicles. When cycle-rickshaws swerve away from their lanes, vehicles coming from behind have to immediately decelerate or change directions without giving indicators to other

vehicles causing a disruption of traffic flow. Likewise, the findings for cycle-rickshaws lane-splitting tendency, it is concluded that when cycle-rickshaws lane-split between stationary vehicles, they move chaotically and randomly in gaps between vehicles. This chaotic movement acts as a hindrance for the motorised vehicles to accelerate and cross intersections in due time. The above findings were corroborated by authors Khan and Maini (1999) and Munigety and Mathew (2016), Agarwal and Lammel (2015) and Parsuvanathan (2015), and Madhu, Sivanandan, et al., (2020)

Cycle-rickshaw's traffic-rule violation also showed influence on the levels of traffic congestion again by reducing the average vehicular speed of the traffic. The findings collected all concluded that cycle-rickshaws do not obey traffic signs and signals. According to respondents and also corroborated by secondary sources, cycle-rickshaws do not understand traffic signs and signals as more than 90 percent of them directly come to urban areas from rural areas (Begum and Sen, 2005). The respondents mentioned that cycle-rickshaws do not obey no-rickshaw entry sign and enter into the main study area routes from adjacent roads where rickshaw movement is supposed to be prohibited. This causes motorised vehicles to reduce their speed especially if the rickshaw comes in front of a motorised vehicle while it is entering. Respondents also showed high disagreement for cycle-rickshaw's level of obeying traffic signs like 'pedestrian crossing', and 'school-ahead' sign which all require cycle-rickshaws to reduce their speed which would otherwise result in accidents. Cycle-rickshaws' level of erratic and impatient behaviour were surveyed about queue-breaking tendency, wrong-way driving and illegal parking where respondents mentioned that due to rickshaws stopping in the roads where they are not supposed to, parking at no-parking zones and road junctions and driving in the wrong-ways, it causes the motorised vehicles on the road to reduce their speed drastically or do hard brakes. Moreover it was supported by interviews and secondary sources that cycle-rickshaws rule-violating movement is because of their tendency to reach the destination first to reduce unproductive hours, and any hindrance against achieving the target amount imposes severe psychological, financial and physical stress which influences them to violate traffic rules in mega-city Dhaka (Al-Madani and Al-Janahi, 2002).

As already discussed in sub-question 1, that levels of service represented the quality of traffic flow on the three roads, signifying that the three roads have forced flow of vehicle which means very high levels of congestion, and SRI index showed that between the three roads, higher levels of congestion exist in Dhaka Central and Dhaka South roads than Dhaka North road due to the difference between the SRI ratio of Dhaka Central and South than Dhaka North. The table below summarizes the findings from the dependent variables for the three study areas.

Road	Distance	Speed in off-peak period (midnight)	Speed in peak period (morning)	Speed in peak period (evening)	Speed Reduction Index (SRI)		Level of service (LOS)	Description of category of LOS
Uttara sector 11 to Mascot Plaza (Dhaka North)	1.6 km	26 km/h	4.8 km/h	4.8 km/h	Morning	Evening	F	Forced vehicle flow
					8.2	8.2		
Mohammadpur bus stop to Asad Gate bus stop(Dhaka North)	1.3 km	16.25 km/h	2.6 km/h	2.32 km/h	Morning	Evening	F	Forced vehicle flow
					8.4	8.6		
Shahbag to Science lab(Dhaka South)	1.4 km	18.66 km/h	2.8 km/h	2.54 km/h	Morning	Evening	F	Forced vehicle flow
					8.5	8.6		

Table 21: Comparison of Speed Reduction Index and Level of Service for the three study areas

Statistical correlations were conducted between the travel time data (dependent variable) and the indicators of the independent variable for each study area which showed statistically significant correlation for Dhaka Central and South. However the results did not show statistical significant results for any of the independent variables for Dhaka North. This is because lower travel time in Dhaka North, therefore lower vehicular speed therefore lower levels of congestion than the other two as seen in the above fig, even though high number of respondents agreed on the movement of cycle-rickshaws that influence traffic congestion. The reason for this could be because of Dhaka North's better physical conditions like wider roads and better traffic management systems like stricter law enforcement for which traffic congestion by cycle-rickshaw movement is minimized. Another reason as corroborated by secondary sources that the socioeconomic characteristics of Dhaka North is higher than the other two therefore, higher income level, and higher ownership of motorised vehicles resulting in low demand for cycle-rickshaws. Furthermore, geographical location of Dhaka North also does not allow commuters from all across Dhaka city to move on the study area route restricting to the movement of Dhaka North only, therefore mostly dominated by motorised vehicles. In addition to that the socioeconomic characteristics of Dhaka Central and South lies in the lower to middle and higher income groups resulting in more number and mixture of motorised and non-motorised vehicles and more demand of cycle-rickshaws that increases more frequent interactions of motorised and non-motorised vehicles. Therefore, it can be concluded that heterogeneousity of a road varies indirectly with the socio-economic characteristics of a neighbourhood which ultimately influences the levels of congestion on its roads. The lower the heterogenousity of vehicles the lesser the interactions between motorised and non-motorised vehicles (cycle-rickshaws) resulting in lower levels of traffic congestion.

To conclude the findings collected from surveys, interviews and secondary sources, the independent variable, 'movement of cycle-rickshaws' has influenced the dependent variable, traffic congestion in the above mentioned ways as discussed under each sub-variable of the independent variable which has eventually reduced the average vehicular speed of the traffic and increased traffic congestion on the three study areas. Statistical correlations proved that the influence on traffic congestion by cycle-rickshaw movement is more for Dhaka Central and Dhaka South than Dhaka North as Dhaka Central and South roads are more

heterogeneous in nature than Dhaka North road.

5.3. Recommendations

From the findings of this research, it is recommended to address the issues of traffic congestion on Dhaka North, Dhaka South and Dhaka Central. Due to the lack of mass transit system in Dhaka City, the inhabitants of Dhaka city rely heavily on the mode of cycle-rickshaws to commute along shorter distances. Furthermore, cycle-rickshaw sector provides employment opportunities to rural migrants. Among 1.5 million rickshaw pullers plying in the mega-city, more than 90 percent of them directly come from the rural parts of Bangladesh (Sohel,2006). Therefore, it is recommended that BRTA (Bangladesh Road Transport Authority) adopt favourable policies to integrate cycle-rickshaws in the overall transportation planning of Dhaka city but innovative policies and design should be ensured to minimize the influence of traffic congestion contributed by cycle-rickshaws. For example, cycle-rickshaws can be recognized as an important feeder road vehicle and roads that are wider can be segregated to accommodate the movement of non-motorised vehicles like cycle-rickshaws and other two and three wheelers. By doing so, the interaction between different speeds and sizes of vehicles are minimized that characterizes the heteogenousity of the road which causes congestion. Furthermore, it is adviced that cycle-rickshaw pullers must be given adequate training and workshops on road traffic signs and signals as secondary data and interview respondents mentioned about rickshaw pullers lack of knowledge on these issues. If rickshaw pullers knowledge about road traffic signs are improved, there will be a significant reduction in traffic congestion and road accidents. Cycle-rickshaws' fitness and license documents must be verified diligently by BRTA before giving them permit to commute along the roads of Dhaka city. Lastly, it is recommended to Dhaka City Corporations (DCC), Dhaka Transport Coordination Authority (DTCA), BRTA (Bangladesh Road Transport Authority) and RAJUK (Rajdhani Unnayan Kartipakkha) to address the issue of land use design and vehicle use on the planning of future urban development in other areas of Dhaka or Bangladesh. By doing so, heterogeneousity of the roads can be projected which will guide in the adoption effective transportation policies in order to minimize traffic congestion in the newly planned areas.

5.4: Areas of future research

In Dhaka city, research done in the past mostly included studies on traffic congestion from supply or demand side of transport management systems that include homogenous traffic characteristics. Most studies did not take into account the heterogeneousity of urban traffic systems in developing cities and how cycle-rickshaw movement respond to these heterogeneous conditions. So, it is recommended that more research is conducted in this arena. For example, research can be conducted on the movement of other commercial vehicles like CNGS, tempos and minibuses and how they respond to heterogeneous conditions in Dhaka city as these commercial vehicles have also been considered responsible for causing traffic congestion.

Moreover, since heterogenousity of a neighbourhood has been identified to be depending on the socioeconomic characteristics of a neighbourhood, future research should be conducted on the relationship between socioeconomic characteristics of users and traffic congestion or income levels of users and traffic congestion or land use patterns and traffic congestion. In addition to that, since there is a lack of mass-transit system in Dhaka city which influences

the increase in cycle-rickshaw trips, there is a need to conduct research on how the lack of mass-transit system or public transportation influence traffic congestion.

Based on the above discussions, future research questions like: ‘’How does the movement of CNGs influence traffic congestion in Dhaka city?’’ ‘’How does income levels influence traffic congestion in Dhaka city?’’ ‘’How does land-use patterns influence traffic congestion in Dhaka city?’’ ‘’ How does the lack of an efficient mass transit system influence traffic congestion in Dhaka city?’; could be attempted to answer.

5.5. Author’s Outlook

Traffic congestion in Dhaka city is caused mainly because of poor land use and transportation planning, poor execution of traffic code of practice, fragmented responsibilities between too many regulatory authorities, violation of traffic rules by vehicle drivers, too many non-registered non-motorised vehicles, poor city and transportation planning, inadequate traffic management resources, lack of mass public transportation system and uncontrollable growth of vehicle ownership (Ahmed, 2017). The results from this study show that cycle-rickshaw movement which is a non-motorised vehicle influence traffic congestion. In recent times, Dhaka has become the growth engine of Bangladesh as greater Dhaka generates one-fifth of the country’s gross domestic product (GDP) and almost half of its formal employment (Wee, 2018). This attracts massive number of people to migrate to Dhaka city every year because of better socio-economic opportunities. Due to a lack of public transportation, cycle-rickshaws are a popular mode of transportation which for its mismanagement and lack of discipline has given rise to excessive traffic congestion. Therefore, urgent attention should be given to this growing influx of population in Dhaka city and the number of cycle-rickshaw trips rising to accommodate this growth. Some of the ways cycle-rickshaw movement can minimize levels of traffic congestion is if cycle-rickshaw movement is segregated from other motorised vehicles. This can be done by prioritizing cycle-rickshaw as a feeder road transport. Nevertheless, the need for a mass public transportation system in Dhaka city is inevitable which against this growing demand of people, which if not met urgently will pose severe threats to the urban environment by increasing traffic congestion,

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Annex 1: Questionnaire for road users

Hi, these questions are for my masters thesis titled *' The influence of the movement of cycle-rickshaws on traffic congestion- A study of heterogenous traffic conditions in Dhaka city.'* Heterogeneous traffic conditions are defined as the traffic consisting of varied vehicles of different speeds and sizes travelling together on the same right of way without having designated lanes. Heterogenous traffic conditions are mostly seen in densely populated developing cities like Dhaka. It is believed that due to the relatively smaller size and slower speed of rickshaws moving on the roads of Dhaka city, they tend to influence the driving behaviour of other larger sized or faster moving vehicles. If you are a driver in Dhaka city, your answers to the following questions below will help me understand the subject matter as a researcher. Please feel free to answer the questions. Thank you.

1. Age
- ○ 18-25
- ○ 26-35
- ○ 36-45
- ○ 46-55
- ○ Above 55 years

2. Gender
- ○ Male
- ○ Female

3. Occupation:
- ○ Driver
- ○ Office worker
- ○ College student
- ○ Middle/High school student
- ○ University Student
- ○ Self-employed
- ○ Others

4. Please select which road do you usually drive along?
- ○ Shahbag to Science Lab
- ○ Mascot Plaza to Uttara Sector 11, welfare Association
- ○ Assad gate bus stop to Mohammadpur bus stop
- ○ None of the above

5. What type of vehicle do you drive? Please select more than one if applicable to you.
- ○ Bus
- ○ Motorcycle
- ○ Cart
- ○ Tempo
- ○ Cargo
- ○ Van
- ○ Jeep
- ○ Microbus
- ○ Minibus
- ○ Taxicab
- ○ Pickup
- ○ Truck
- ○ Cng

- Ambulance

6. Do you travel from point A to point B?Please select one.
  - Yes, I travel from point A to point B
  - Yes, I travel from point B to A
  - I travel along both the roads
  - None of the above

7. Do you travel from point B to point A
  - Yes, I travel from Point B to A
  - I travel along both the roads
  - None of the above

8. What time of the day do you travel to reach your destination?
  - early morning (4-8) a.m
  - late morning (8 am- 12 noon)
  - afternoon (12-3) p.m
  - late noon (3-6) p.m
  - evening (6-9) p.m
  - late evening 9 p.m-12 a.m
  - midnight period (12 a.m – 3 a.m)

9. What time of the day do you travel to return from your destination?
  - early morning (4-8) a.m
  - late morning (8 am- 12 noon)
  - afternoon (12-3) p.m
  - late noon (3-6) p.m
  - evening (6-9) p.m
  - late evening 9 p.m-12 a.m
  - midnight period (12 a.m – 3 a.m)

10. How long does it take you to drive from point A to point B in the morning?
  - 5-15 mins
  - 15-30 mins
  - 30-45 mins
  - 45-60 mins

11. How long does it take you to drive from point B to A in the evening?

  - 5-15 mins
  - 15-30 mins
  - 30-45 mins
  - 45-60 mins

Please rate how strongly you agree or disagree with each of these statements

19. Rickshaws move away from its lane and comes in front of my moving vehicle.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

20. Rickshaw moves from its lane and comes very close adjacent my side while I am driving.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

21. Rickshaw comes very close to my rear while I am driving.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

22. Rickshaw obeys its queue and doesn't take a u-turn to break its queue.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

23. Rickshaws swerve away from its lane which disrupts my motion.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

24.Rickshaws always obey 'no-rickshaw entry' sign.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

25. Rickshaws always obey 'one-way' road sign.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

26. Rickshaws reduce their speed when they see 'school ahead' sign.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

27. Rickshaws reduce their speed when they see the pedestrian crossing sign.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

28. Rickshaws obey signals from traffic police.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

30. Rickshaws come in front of me from wrong direction which reduces the speed of my vehicle.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

33. Rickshaws halt at random places to leave/take passengers which slows down my vehicle.

1	2	3	4	5
Strongly disagree	disagree	neutral	agree	strongly agree

Annex 2: Structured interviews

Hi, these questions are for my masters thesis titled *' The influence of the movement of cycle-rickshaws on traffic congestion- A study of heterogenous traffic conditions in Dhaka city.'* Heterogeneous traffic conditions are defined as the traffic consisting of varied vehicles of different speeds and sizes travelling together on the same right of way without having designated lanes. Heterogenous traffic conditions are mostly seen in densely populated developing cities like Dhaka. It is believed that due to the relatively smaller size and slower speed of rickshaws moving on the roads of Dhaka city, they tend to influence the driving behaviour of other larger sized or faster moving vehicles. If you are a driver in Dhaka city, your answers to the following questions below will help me understand the subject matter as a researcher. Please feel free to answer the questions. Thank you.

Traffic police officers (3 interviews from 3 study areas)

1. What is your current occupation?
2. Please describe your daily routine as a traffic police officer.
3. What are your daily tasks and responsibilities?
4. How long do you patrol everyday on this road?
5. How many officers patrol daily?
6. What do you think is the situation of traffic congestion of this road? Please mention the difference in the level of traffic congestion between weekdays and weekends if applicable.
7. What do you think are the main causes of traffic congestion on this road?
8. What time do you consider as peak and non-peak period on this road?
9. For how many hours in a day does this road face traffic congestion?

10. How do you think rickshaws commuting on this road with the presence of vehicles of different speed and sizes influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
11. How do you think rickshaws commuting on this road without maintaining any lane discipline influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
12. Are the traffic police trying to improve this situation? How are you doing so?
13. Do you think rickshaws obey traffic rules and regulations on the road?
14. How often do they violate traffic rules and what kind of rules do they violate?
15. How do you think rickshaws violating traffic rules and regulations influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
16. What kind of challenges do you face in maintaining a smooth operation of traffic flow on this road when dealing with rickshaws?
17. Please describe the difference of traffic congestion between a day when rickshaw flow is heavy as opposed to when it is not so heavy.
18. What do you think are the main causes of unpredicatable and erratic behavior of rickshaw pullers? What are your recommendations in solving this issue.

Rickshaw passengers – 2 interviews from 2 study areas

1. How many times a day do you travel by rickshaws?
2. Where do you usually travel by rickshaws?
3. What time do you consider as peak and non-peak period on this road?
4. What do you think is the situation of traffic congestion of this road? Please mention the difference of the level of traffic congestion between weekdays and weekends if any.
5. What do you think are the main causes of traffic congestion on this road?
6. How do you think rickshaws commuting on this road with the presence of vehicles of different speed and sizes influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
7. How do you think rickshaws commuting on this road without maintaining any lane discipline influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
8. Please comment on how you have been personally affected while travelling on a rickshaw because of the above mentioned issues.
9. According to your experience, do you think rickshaws obey traffic rules and regulations on this road?
10. How often do they violate traffic rules and what kind of rules do they violate?
11. How do you think rickshaws violating traffic rules and regulations influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
12. Has your commute by rickshaws always been pleasant or unpleasant? Please comment why it is pleasant or unpleasant.
13. Do you believe rickshaw travel behavior is systematic and predicatable or erratic and unpredictable?
14. Please describe some erratic and unpredictable behavior of rickshaws that you observed while travelling by rickshaws.
15. What do you think are the main causes of unpredicatable and erratic behavior f rickshaws movement? What are your recommendations in solving this issue.

Pedestrians (2 interviews from 2 study areas)

1. Do you commute along this road on a regular basis?
2. What do you think is the situation of traffic congestion of this road? Please mention the difference of the level of traffic congestion between weekdays and weekends if applicable.
3. What do you think are the main causes of traffic congestion on this road?
4. What time do you consider as peak and non-peak period on this road?

5. For how many hours in a day does this road face traffic congestion?
6. How do you think rickshaws commuting on this road with the presence of vehicles of different speed and sizes influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
7. How do you think rickshaws commuting on this road without maintaining any lane discipline influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
8. Do you think rickshaws obey traffic rules and regulations on the road?
9. How often do they violate traffic rules and what kind of rules do they violate?
10. Are the traffic police trying to improve this situation? How are they doing so?
11. How do you think rickshaws violating traffic rules and regulations influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
12. Please describe a difference in a day of traffic congestion with heavy and not-so heavy flow of rickshaws on this road.
13. What do you think are the main causes of unpredictable and erratic behaviour of rickshaw pullers? What are your recommendations in solving this issue.

Vehicle drivers (2 interviews from 2 study areas)

1. Do you commute along this road on a regular basis?
2. What do you think is the situation of traffic congestion of this road? Please mention the difference of the level of traffic congestion between weekdays and weekends if applicable.
3. What do you think are the main causes of traffic congestion on this road?
4. What time do you consider as peak and non-peak period on this road?
5. For how many hours in a day does this road face traffic congestion?
6. How do you think rickshaws commuting on this road with the presence of vehicles of different speed and sizes influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
7. How do you think rickshaws commuting on this road without maintaining any lane discipline influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
8. Do you think rickshaws obey traffic rules and regulations on the road?
9. How often do they violate traffic rules and what kind of rules do they violate?
10. Are the traffic police trying to improve this situation? How are they doing so?
11. How do you think rickshaws violating traffic rules and regulations influence the overall vehicular speed of the traffic flow or cause traffic congestion on this road?
12. Please describe a difference in a day of traffic congestion with heavy and not-so heavy flow of rickshaws on this road.
13. What do you think are the main causes of unpredictable and erratic behaviour of rickshaw pullers? What are your recommendations in solving this issue.

Annex 3: Correlations

Dhaka Central

Correlations

		morning travel time	19. level of overtaking	20. level of travelling abreast	21. level of tailgating	23. level of swerving	18. level of lane-splitting	24. obeying 'no-rickshaw entry' sign.	26. obeying 'school ahead' sign	27. obeying pedestrian crossing sign.	28. obeying signals from traffic police.	22. obeying queues	30. level of wrong-way driving	33. level of illegal parking	evening travel time
morning travel time	Correlation Coefficient	1.000	.329**	.329**	.406**	.221*	.048	.049	.422**	.285**	-.001	-.066	.393**	.221*	.761**
	Sig. (2-tailed)	.	.000	.000	.000	.011	.585	.581	.000	.001	.988	.454	.000	.011	.000
	N	131	131	131	131	131	131	131	131	131	131	131	131	131	131
19. level of overtaking	Correlation Coefficient	.329**	1.000	1.000**	.467**	.192*	.207*	.040	.338**	.105	.127	.055	.254**	.083	.221*
	Sig. (2-tailed)	.000	.	.	.000	.026	.016	.647	.000	.227	.145	.529	.003	.338	.010
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
20. level of travelling abreast	Correlation Coefficient	.329**	1.000**	1.000	.467**	.192*	.207*	.040	.338**	.105	.127	.055	.254**	.083	.221*
	Sig. (2-tailed)	.000	.	.	.000	.026	.016	.647	.000	.227	.145	.529	.003	.338	.010
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
21. level of tailgating	Correlation Coefficient	.406**	.467**	.467**	1.000	.203*	.128	-.030	.536**	.357**	.031	-.027	.384**	.131	.336**
	Sig. (2-tailed)	.000	.000	.000	.	.019	.140	.731	.000	.000	.724	.755	.000	.130	.000
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
23. level of swerving	Correlation Coefficient	.221*	.192*	.192*	.203*	1.000	.010	.227**	.259**	-.012	.058	.111	.287**	.035	.186*
	Sig. (2-tailed)	.011	.026	.026	.019	.	.906	.008	.003	.894	.504	.202	.001	.689	.032
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
18. level of lane-splitting	Correlation Coefficient	.048	.207*	.207*	.128	.010	1.000	.088	.193*	.089	.146	.350**	.181*	-.079	-.028
	Sig. (2-tailed)	.585	.016	.016	.140	.906	.	.310	.026	.305	.092	.000	.036	.363	.752
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
24. obeying 'no-rickshaw entry' sign.	Correlation Coefficient	.049	.040	.040	-.030	.227**	.088	1.000	.010	.041	.142	.256**	.025	.074	.094
	Sig. (2-tailed)	.581	.647	.647	.731	.008	.310	.	.909	.639	.103	.003	.776	.393	.280
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
26. obeying 'school ahead' sign	Correlation Coefficient	.422**	.338**	.338**	.536**	.259**	.193*	.010	1.000	.386**	.151	-.067	.449**	.044	.226**
	Sig. (2-tailed)	.000	.000	.000	.000	.003	.026	.909	.	.000	.082	.445	.000	.612	.009
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
27. obeying pedestrian crossing sign.	Correlation Coefficient	.285**	.105	.105	.357**	-.012	.089	.041	.386**	1.000	.203*	.089	.287**	.064	.278**
	Sig. (2-tailed)	.001	.227	.227	.000	.894	.305	.639	.000	.	.019	.308	.001	.466	.001
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
28. obeying signals from traffic police.	Correlation Coefficient	-.001	.127	.127	.031	.058	.146	.142	.151	.203*	1.000	.133	.089	-.089	.053
	Sig. (2-tailed)	.988	.145	.145	.724	.504	.092	.103	.082	.019	.	.126	.306	.307	.546
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
22. obeying queues	Correlation Coefficient	-.066	.055	.055	-.027	.111	.350**	.256**	-.067	.089	.133	1.000	.068	-.059	.045
	Sig. (2-tailed)	.454	.529	.529	.755	.202	.000	.003	.445	.308	.126	.	.433	.500	.608
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
30. level of wrong-way driving	Correlation Coefficient	.393**	.254**	.254**	.384**	.287**	.181*	.025	.449**	.287**	.089	.068	1.000	.221*	.301**
	Sig. (2-tailed)	.000	.003	.003	.000	.001	.036	.776	.000	.001	.306	.433	.	.010	.000
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134
33. level of illegal parking	Correlation Coefficient	.221*	.083	.083	.131	.035	-.079	.074	.044	.064	-.089	-.059	.221*	1.000	.298**
	Sig. (2-tailed)	.011	.338	.338	.130	.689	.363	.393	.612	.466	.307	.500	.010	.	.000
	N	131	134	134	134	134	134	134	134	134	134	134	134	401	134
evening travel time	Correlation Coefficient	.761**	.221*	.221*	.336**	.186*	-.028	.094	.226**	.278**	.053	.045	.301**	.298**	1.000
	Sig. (2-tailed)	.000	.010	.010	.000	.032	.752	.280	.009	.001	.546	.608	.000	.000	.
	N	131	134	134	134	134	134	134	134	134	134	134	134	134	134

ion is significant at the 0.01 level (2-tailed).

on is significant at the 0.05 level (2-tailed).

Dhaka North

Correlations

		morning travel time	19. level of overtaking	20. level of travelling abreast	21. level of tailgating	23. level of swerving	18. level of lane-splitting	24. obeying 'no-rickshaw entry' sign.	26. obeying 'school ahead' sign	27. obeying pedestrian crossing sign.	28. obeying signals from traffic police.	22. obeying queues	30. level of wrong-way driving	33. level of illegal parking	evening travel time
morning travel time	Correlation Coefficient	1.000	-.082	-.131	-.159	.029	-.019	-.084	-.124	.136	.002	-.086	-.084	-.180*	.608**
	Sig. (2-tailed)	.	.350	.132	.067	.741	.827	.337	.155	.120	.980	.323	.334	.038	.000
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
19. level of overtaking	Correlation Coefficient	-.082	1.000	.593**	.376**	.396**	.459**	.068	.317**	.244**	.290**	-.270**	.050	.327**	-.063
	Sig. (2-tailed)	.350	.	.000	.000	.000	.000	.435	.000	.005	.001	.002	.566	.000	.472
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
20. level of travelling abreast	Correlation Coefficient	-.131	.593**	1.000	.476**	.407**	.239**	.056	.220*	.167	.117	-.249**	.184*	.333**	-.121
	Sig. (2-tailed)	.132	.000	.	.000	.000	.006	.525	.011	.055	.181	.004	.034	.000	.165
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
21. level of tailgating	Correlation Coefficient	-.159	.376**	.476**	1.000	.424**	.375**	.006	.092	.046	.004	-.032	.032	.271**	-.032
	Sig. (2-tailed)	.067	.000	.000	.	.000	.000	.947	.291	.596	.963	.711	.713	.002	.716
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
23. level of swerving	Correlation Coefficient	.029	.396**	.407**	.424**	1.000	.228**	.076	.204*	.271**	.091	-.193*	.144	.152	.077
	Sig. (2-tailed)	.741	.000	.000	.000	.	.009	.386	.019	.002	.301	.026	.099	.083	.377
	N	132	132	132	132	132	132	132	132	132	132	132	132	132	132
18. level of lane-splitting	Correlation Coefficient	-.019	.459**	.239**	.375**	.228**	1.000	.078	.121	.229**	.194*	-.125	-.029	.099	.011
	Sig. (2-tailed)	.827	.000	.006	.000	.009	.	.371	.164	.008	.026	.151	.740	.255	.903
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
24. obeying 'no-rickshaw entry' sign.	Correlation Coefficient	-.084	.068	.056	.006	.076	.078	1.000	.251**	.054	.035	.383**	.238**	.071	-.184*
	Sig. (2-tailed)	.337	.435	.525	.947	.386	.371	.	.004	.535	.686	.000	.006	.416	.034
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
26. obeying 'school ahead' sign	Correlation Coefficient	-.124	.317**	.220*	.092	.204*	.121	.251**	1.000	.441**	.419**	-.158	-.037	.218*	-.122
	Sig. (2-tailed)	.155	.000	.011	.291	.019	.164	.004	.	.000	.000	.070	.675	.012	.163
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
27. obeying pedestrian crossing sign.	Correlation Coefficient	.136	.244**	.167	.046	.271**	.229**	.054	.441**	1.000	.530**	-.048	-.042	.051	-.018
	Sig. (2-tailed)	.120	.005	.055	.596	.002	.008	.535	.000	.	.000	.580	.634	.560	.834
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133

28. obeying signals from traffic police.	Correlation Coefficient	.002	.290**	.117	.004	.091	.194*	.035	.419**	.530**	1.000	-.168	-.175*	.231**	-.043
	Sig. (2-tailed)	.980	.001	.181	.963	.301	.026	.686	.000	.000	.	.053	.044	.007	.621
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
22. obeying queues	Correlation Coefficient	-.086	-.270**	-.249**	-.032	-.193*	-.125	.383**	-.158	-.048	-.168	1.000	.133	-.073	-.249**
	Sig. (2-tailed)	.323	.002	.004	.711	.026	.151	.000	.070	.580	.053	.	.127	.404	.004
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
30. level of wrong-way driving	Correlation Coefficient	-.084	.050	.184*	.032	.144	-.029	.238**	-.037	-.042	-.175*	.133	1.000	.141	-.193*
	Sig. (2-tailed)	.334	.566	.034	.713	.099	.740	.006	.675	.634	.044	.127	.	.106	.026
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
33. level of illegal parking	Correlation Coefficient	-.180*	.327**	.333**	.271**	.152	.099	.071	.218*	.051	.231**	-.073	.141	1.000	-.092
	Sig. (2-tailed)	.038	.000	.000	.002	.083	.255	.416	.012	.560	.007	.404	.106	.	.294
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133
evening travel time	Correlation Coefficient	.608**	-.063	-.121	-.032	.077	.011	-.184*	-.122	-.018	-.043	-.249**	-.193*	-.092	1.000
	Sig. (2-tailed)	.000	.472	.165	.716	.377	.903	.034	.163	.834	.621	.004	.026	.294	.
	N	133	133	133	133	132	133	133	133	133	133	133	133	133	133

is significant at the 0.05 level (2-tailed).

is significant at the 0.01 level (2-tailed).

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