Chapter I

Introduction

"Transportation is a measure of the relationship between areas and is, therefore, an essential aspect of geography" – Ullman, 1954.

1.1 Introduction

Transportation system forms a measure of relationships between the regions and therefore a very crucial component of geography (Ullman, 1954). It is also stated that the transportation is essentially a geographic phenomenon (Hurst, 1974). However, the geography of transportation comes under the purview of economic geography, dealing with the study of all aspects of the transportation network that is related to a geographical area (Briney, 2020). It is the prime link between the spatial organizations and the mainstay for spatial processes and spatial patterns. Therefore, transportation implies a means or a channel of movement of humans and materials between the regions. It is also one of those activities of human society which appears almost universal. Because in everyday life people always moves over places for a different purpose which reduces the spatio-temporal gap between products and producers of any services with the consumers. The term 'transportation' has been defined as "all means of travel and moving person and goods from place to place' (New Standard Encyclopaedia, 1990) and Kansky (1963) has defined the term 'network' as "meshed of the fabric of intersecting lines and interstices". Whereas, to the geographers, it is 'a set of spatial locations which are interconnected within a system by numerous routes and lines"

Human society has always been fundamentally based on the movement of people and products. There has been a huge increase in mobility and accessibility as a result of modern economic processes (Rodrigue et al, 2006). The estimation of the meaning of transportation is different in different domains. It may be understood by planners, engineers, economists, and geographers with different senses as they studied the same with different perspectives. To geographers, transportation geography is studied in terms of spatial expression examining the geographical pattern of transport (Vaidya, 1998). The subject matter of transport geography can be categorised as follows:

a) Geographical pattern and distribution of the transportation system.
b) Flow analysis of commodities and traffic between the places.
c) Study of nodes and links over space and their impact on regional developments.
d) Impact of transportation on the natural environment & socio-economic conditions.

The transportation system of any place plays an important role in the development of the region as the process of import and export of various resources depends on the

transportation facilities. Today society has become increasingly dependent upon their transportation network system, be it roadways, railways, airways or waterways to support a wide range of activities between the places. But the problem arises when the demand for transport network for their use exceeds the capacity, which leads to traffic congestion. Travellers frequently complain about traffic because it stretches their journeys and reduces the amount of time they have for other pursuits. Truck drivers gripe about it because it lowers their output and raises their operating expenses. Congestion on the roads is a problem for those who provide transit services because it necessitates more buses and drivers. Congestion also raises operating expenses, emissions of air pollutants, and fuel use. (Falcocchio and Levinson, 2015). Thus, with the problem of traffic congestion, multiple concerns arises which needs to be resolved immediately.

Transportation network analysis generally provides an insight on the potential traffic implications associated with the development of well managed transportation system which helps to the overall urban development. Analysis of transportation network typically includes the examination of existing road and traffic conditions; analysis of structural properties of roads; circulation of traffic in terms of traffic flow analysis; and the problems faced by traffic and its future planning to mitigate the problems.

1.2 Concept of transportation network

The word *'transport'* was derived from two Latin words, one is *'trans'* meaning *'across'* and the other is *'portare'* meaning *'to carry'*. The concept of transportation came into account because of the inter-regional disparity of resources, labourers, and capital in the real world. Transportation is defined as any sort of movement, including the movement of people and products both within and between locations. In a larger sense, transport denotes the movement of material from a zone of abundance to a region of deficiency through the generation of an imbalanced force of energy, either naturally or artificially. There are various means of transportation based on the ways, the motives and the vehicles known as *'modes'*. According to Saxena (2005), transport is an indispensable feature of contemporary life, there has been an ever-growing interest in the subject of transport geography which generally involves with two different aspects: the first one is a vehicle or unit of carriage and another one is the medium of transportation upon which vehicle will move. He also stated that the choice of medium determines the type and design of the vehicle. For instance, across the highly undulated topography, rocky ground and swamps, the medium to transport goods and materials 'vehicles' can only be a domesticated animal or human themselves. Taking energy source as the basis for the categorization, transportation can be categorised into the following groups

a) Human and animal driven transportation
b) Transportation by physical energy of nature i.e. wind and running water energy
c) Transportation by mechanical energy

Based on the nature of routes following categories are there

a) Land routes include roadways, railways, pathways
b) Water routes include inland and sea or ocean routes
c) Air routes

Classification on the basis of modes of transportation includes

a) Human and animal driven vehicle
b) Automobile
c) Rail
d) Ship
e) Aeroplane

As per India Transport Report: Moving India to 2032 of the National Transport Development Policy Committee (NTDPC) transport system are of five types such as

a) Railways,
b) Roads and Road Transport,
c) Civil Aviation,
d) Port and Shipping,
e) Urban Transport.

According to Rodrigue et al (2006) "Transport modes are the means by which passengers and freight achieve mobility. They are mobile transport assets and fall into one of three basic types; land (road, rail, and pipelines), water (shipping), and air".

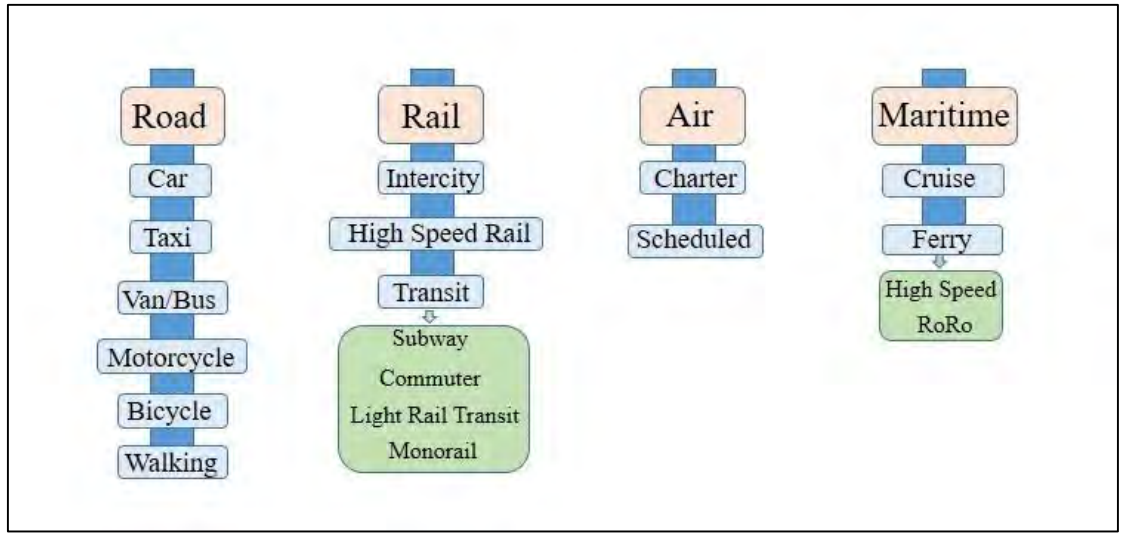

Fig. 1.1 Main passenger modal options (Source: Rodrigue, et al, 2017)

Different modes of transportation are distinctly designed to carry passengers and freight, but some of them can carry a combination of both. On the basis of modal choices, inland transport in India are of four categories, such as:

a) Pathways (by head loads or pack animals)
b) Roadways (by vehicular and non-vehicular carriage)
c) Railways (by passenger trains and freight trains) and
d) Tramways (by passenger trams)

The transportation network of any country act as a veins system of the human body and the importance of transportation varies with the geographical location of the country (Hoyle, 1973; Morrill, 1974). Such as, for an island country, water transportation is the best mode of traffic and commodity flow, whereas remote territories of Alaska roads don't reach many locations so air transportation is a preferred method. But for large landmasses, waterways are very much limited and air transportation is quiet expensive so road transportation is the most efficient method of moving both people and goods. Transportation system contributes to the development of any country or region in terms of economy, social and cultural aspects. The objective of production of any services or commodities is to fulfil the needs of people and the transportation system acts as a mediator between both the row material- production unit and products – distribution to fulfil the demands. In India, road transportation is quiet convenient and faster especially for less distance. The transportation cost is the influencing factor on consumer cost for commodities. Reduced transport costs might save resources which results in more production. As well as, the cheap commuting cost might give access to better jobs. Transportation also plays an important role in country's economy. *According to estimates, 20 to 30 percent of agricultural, horticultural, and forest produce is lost due to a lack of rural roads or bad road conditions, which makes it difficult to transport these goods for consumer needs.*[1]

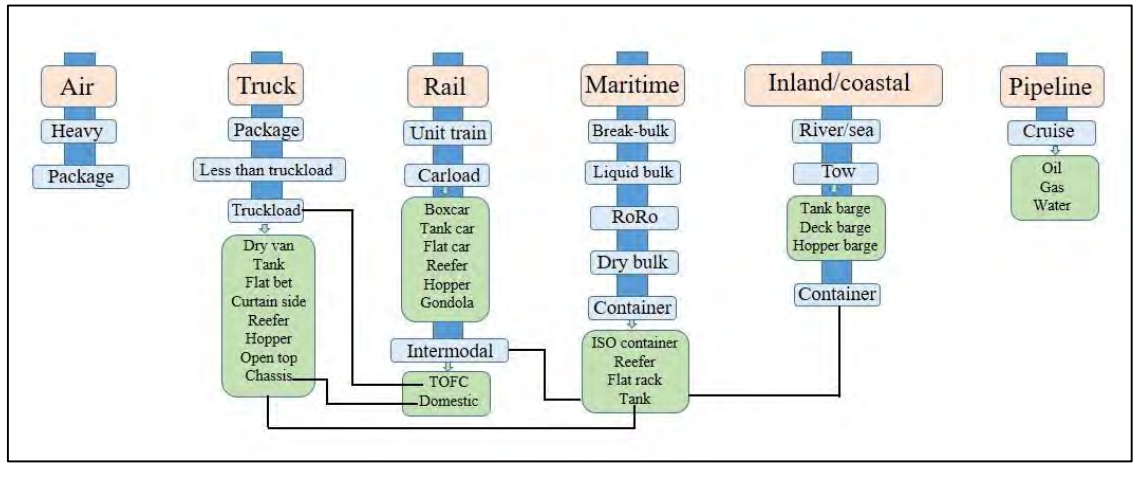

Fig. 1.2 Main freight modal options (Source: Rodrigue, et al, 2017)

[1] http://www.pbr.co.in/2015/may.aspx

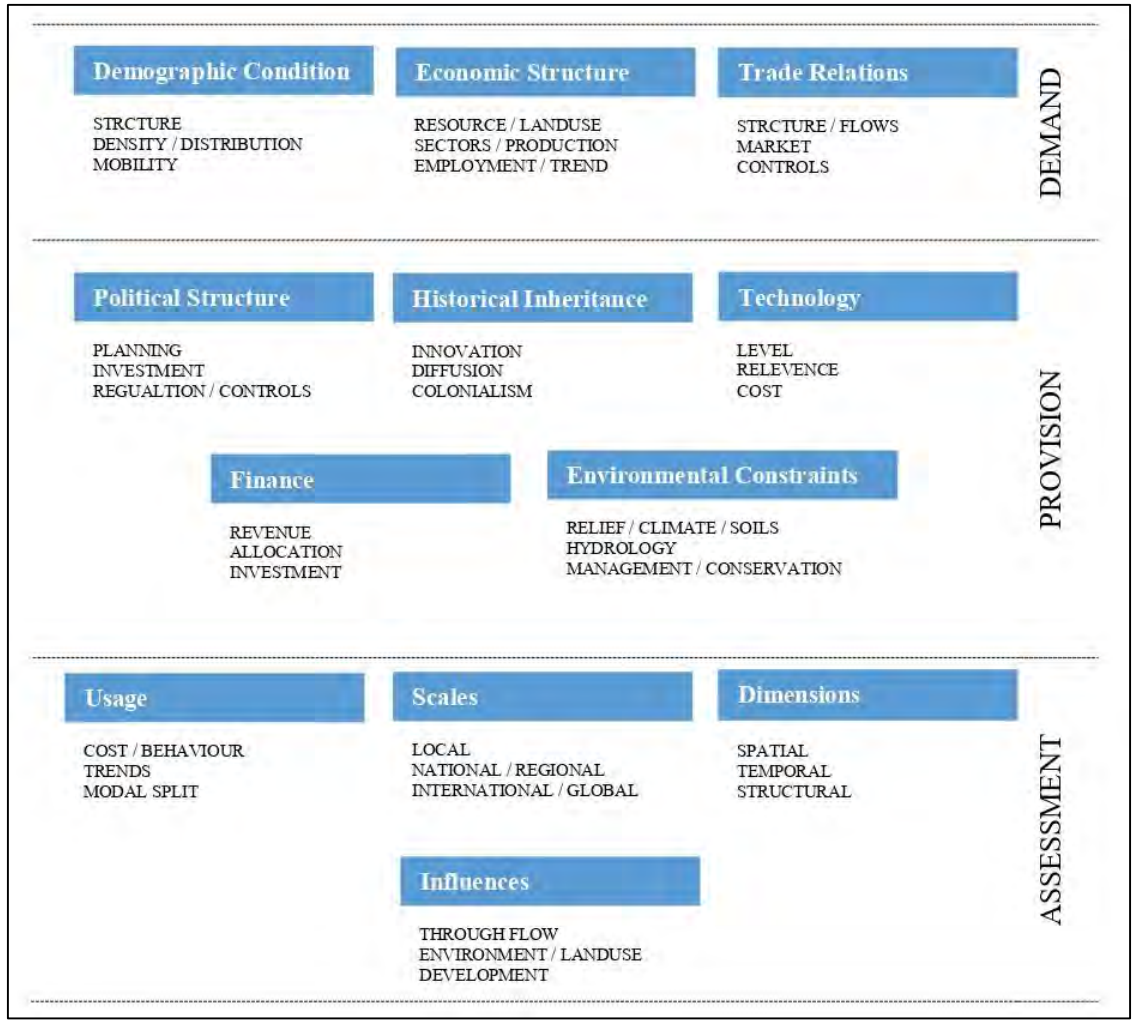

Fig. 1.3 Factors involved in transportation: Demand, Provision, and Assessment (Saxena, 2005)

According to Saxena (2005), there are three factors which may involve in transportation system of any place such as demand, provision and assessment (Fig. 1.3). Demand factor includes demographic conditions, economic structures and trade relations whereas the provision factors deals with the political structures, historical inheritance of the place, technology involved in the system, finance and environmental constraints. Assessment factor is associated with the usage of transportation system, their scale or expansion, dimensions and influences. The present study will completely be focused in the roads and road transport systems.

According to The World Bank (2011) transport sector of India is very large and diverse as well, it serves nearly 1.1 billion people. In 2007, the sector contributed about 5.5 % to the total GDP of the country, with road transportation contributing the maximum share. Demand for transportation services and infrastructure has increased since the early 1990s thanks to India's expanding economy. However, the industry is proving to be a drag on the economy as a result of its inability to keep up with the increase in demand. Therefore, the sector needs to be significantly improved in order to support the nation's ongoing economic growth and to lower poverty. The primary means of transportation in India

nowadays is the road system. They transport more than 60% of the nation's freight and approximately 85% of its passenger traffic. India's motorway network has a density of 0.66 kilometres of roads per square kilometre of land, which is far higher than China's (0.16 kilometres) or Brazil's (0.20 kilometres). However, 33 percent of India's villages lack access to all-weather roads, and the majority of its highways are narrow, congested, and of poor surface quality.

1.3 Road transport network

Road transport network is primarily designed to connect local resources and people to distant markets and population centres. Thus it supports the urban system development (Shreelekha et.al. 2015). Ministry of Road Transport and Highways (GoI), has classified the road transportation system of India under six categories. Such as

a) National Highways (NH)
b) State Highways (SH)
c) Other Public Works Department (PWD) Roads
d) Rural Roads (Panchayat Raj Roads and JRY & PMGSY Roads)
e) Urban Roads
f) Project Roads

They have also highlighted the fact that India has the second-largest road network in the world. Basic Road Statistics of India (2015-16) says, out of 56.03 lakh kilometres of roadway 101011 kilometres (1.80%) are of National Highways, 176166 kilometres (3.14%) are of State Highways, 561940 kilometres (10.03%) are district roads, whereas 3935337 kilometres (70.23%) are rural roads, 509730 kilometres (9.10%) are urban and rest (5.70%) are project roads. The five states with the largest road networks are Maharashtra, Uttar Pradesh, Karnataka, Assam, and West Bengal which account for a share of 43.11% of total road length of the country. Being an international corridor Siliguri has a great road network connectivity with the neighbouring countries and states. The NH 10, NH 110 and SH 12A are the regional roads that pass through the Siliguri.

1.4 Related terminologies

Considering the different concepts related to road transport, there is felt a need to define the various aspects of a road in a particular space and its characteristics for the present study. Some of them mentioned are

- **Accessibility:** Accessibility is the measure used to determine the ease with which a place is reached by a mode of transportation, and the interaction with the place reached.
- **Connectivity:** Connectivity of the road is used to define the degree of connection between all the vertices in a road network, and is one of the most important structural properties of the network. The degree of connection indicates the level of spatial network development.

- **Traffic flow:** The count of moving vehicles through a particular route during a specified period of time in a specific direction is known as the traffic flow.
- **Average travel speed:** The ratio between total distances travelled and the time taken to travel on a vehicle along a route is called average travel speed. According to Calcutta Metropolitan Planning Organization (1967), the average travel speeds for street and highway facilities are determined by operating a test car over the length of the street several times at speeds at which other vehicles are operating and recording the total time in transit for each run.
- **Off-street and on-street parking:** Off street parking space is the space which may be either indoor or outdoor. This kind of parking may include private lots, garages and driveways and the vehicles are parked in these spaces rather than on the roads meant for moving vehicles and man. On the other hand, if the vehicles are parked on the either side of a road or street itself, it is known as on-street parking.
- **Urban service facilities:** The term *urban service* is often used interchangeably with *public service* or *municipal service* or *local service* (Baer, 1985). The services offered by municipalities are those must vital to the preservation of life (police station, fire station, sanitation facility, healthcare system etc.), public enlightenment (schools, colleges, universities and libraries), liberty (court and prosecutors), property (zoning, planning and taxing), pursuit of happiness (parks and recreation), promotion of general welfare (transit and social service), and domestic tranquillity (housing and environmental protection).

1.5 The urban road transport system

Transportation is the underlying force in the location, growth, rank-size and functional differentiation of cities. An adequate, cheap and efficient passenger transport facility is an essential requirement of urban life. The city develops at foci or break of transportation points. Thus the transportation system of both the inter-city and intra-city is of prime concern for both the urban and transport geographer. With the growing urbanization and rapid growth of transportation, it is necessary to examine the patterns of transport and the associated problems (Saxena, 2005). As per Indian Road Congress (IRC: 86, 1983), the roads in any urban areas may be classified either based on the number of lanes provided within an undivided/divided cross-section, or by their functions in the total urban road network.

1.5.1 Types of road based on the number of lanes

a) Undivided urban road: the undivided urban road is which permits traffic flow in both the direction without segregating the directional movement through some physical dividers, such as a central verge or median. These roads are also termed as 2-lane undivided, 4-lane undivided or 6-lane undivided depending upon the number of lanes available for the use of traffic.

b) Divided urban road: the divided urban road is one where the traffic in two directions moves in segregated lanes because of the presence of a physical divider. These

roads are known as 4-lane divided, 6-lane divided or 8-lane divided urban roads by the number of traffic lanes available.

1.5.2 Types of road based on the functions

Functional classification of the urban road is based on the hierarchy of the urban roads in the total road network. Besides the expressways and freeways, urban roads can be classified into the following four categories.

a) Arterial roads: The Traffic Engineering Handbook describes *arterials* as being either principal or minor, both classes serves to carry longer distance flow between important centres of activity. It joins CBD with outside residential areas. Generally, parking and loading-unloading is prohibited along the arterial roads. The roadway carries long-distance vehicle traffic to a specific area. Calcutta Metropolitan Planning Organization (CMPO, 1967) has defined the concept of arterial roads as "a roadway similar to an expressway, but of a lower order in terms of design, speed, and capacity. Arterials roads generally have no access controls and most intersections are at-grade with traffic signal controls provided at the intersection of two arterials. Because of these characteristics, arterials have a dual function; they serve through-traffic movements as well as provide access to abutting land". Indian Road Congress (IRC: 86-1983) has defined the arterial road as a street which primarily for through traffic, usually on a continuous route.

b) Sub-arterial roads: The roadways which carry through-traffic between a specific area and arterial roads are known as sub-arterial roads. The sub-arterial roadways serve as connectors/support to the arterial roads. These roads generally offer a lower level of traffic mobility than arterials.

c) Collector streets: the streets for collecting and distributing traffic from and to local streets are known as collector streets. These streets also provide people to access other arterial and sub-arterial roads.

d) Local streets: the streets which primarily for access to the residence, business or other abutting property.

For the present research, classification of the roads based on functions have been considered.

1.6 Review of literature

Traditionally transportation has been studied as one of the typical fields in engineering, planning, economics, and geography as structural properties in regional studies. The study of transportation system has always been a prime concern in planning and road engineering for a very long and it has emerged as a new topic of concern very recently as the transportation system has a direct effect on the social and economic process of development. Numerous pieces of literature are available on traffic engineering, hydraulic engineering, pavement engineering, designing of bridges, designing of

flyovers, mass transit, and rapid transit in the field of planning and engineering. While in the field of social sciences are getting more attention day by day. Within the social sciences, the interest in the study of transportation was initially started in the discipline of economics and the emphasis was given to develop different models to determine the location of various economic activities to minimize the transportation cost and maximize the profit. For instance, Weber's least-cost location model and Losch's profit maximization theory a significant emphasis was given to the role of transport in industrial location and development (Weber, 1909; Losch, 1954). With the advent of the quantification in the field of geography, however, a new beginning for transportation system analysis has been started with several existing possibilities. Such as models on commodity flow or the gravity and entropy models, and the analysis of interaction matrices. An overview regarding the present study can be made if we look into some of the previous works related to transport network analysis. The analysis of transportation network and its interaction with the other phenomenon was first introduced in later part of the 19th century and got importance during early 1850s. According to C. H. Cooley (1984) *".... there can be no adequate theory of transportation which has regard only to some one aspect of its social functions, as the economic aspect. This is not only aspect, not can we only truly say that it is more important than the others. All are co-ordinate, equally indispensable to social progress".*

A German Geographer, J.G. Kohl (1850), has created asset of network to serve the inhabitants in an idealized city. In the year 1935 this idea was taken up by, W. Christaller has also introduced his concept of central places in South Germany. Both the ideas lead to a significant description of transportation elements such as links, nodes, stocks and flows. Till the year 1950, majority of the works on transportation were from Europe compared to the other parts of the world.

As the pioneers in the field of transportation geography Ullman and Mayer (1954) have marked out the objective and the nature of transportation geography. According to them, the prime concern of the field is associated with the study of various features of traffic – volume, origin, destination, rate structure and the physical facilities.

Garrison and Marble (1961), have designed some techniques of graph theory to investigate the theoretical and empirical structure of a transportation network.

Garrison (1962), is known for revitalising transportation geography. He has investigated the connectivity of the inter-state highway systems of 45 places in south eastern part of United States and explored many techniques of graph theoretical measurements in the analysis of national and regional economies.

Similarly, Kansky (1963), has also studied abstract graph theory to analyse the hypothetical relationship of the structure of transport system with the level of economic development and developed connectivity indices of cyclomatica number, alpha, beta and gamma.

According to Singh (1964), one of the major objectives of transportation geography is to use transportation expressions as a tool for analysing the other geographical phenomena.

Singh (1966), have analysed transportation network of Uttar Pradesh to measure its physical accessibility in terms of different isodromes. According to his study, Doab region of the river Ganga and Yamuna is highly accessible due to its well-developed railways and roadway network. He has also discussed about regional and inter-regional measures of effectiveness of transport network.

Haggett and Chorley (1969) have focused on the topologic structures, graph theory and their measures based on gross characteristics network like beta index, alpha index, gamma index, etc. and the measures based on shortest path characteristics like diameter, accessibility index, dispersion index, etc. in their book entitled 'Network Analysis in Geography'.

Gauthier (1973), has noted three possible impacts of transportation and development, viz. i) positive, ii) permissive, and iii) negative. In the same year Wheeler (1973) stressed on the need for study of transportation in societal perspective underlining its contribution to the process of industrialization, economic specialization, and socio-economic development.

Hay (1973) also provides an overview of topological approaches to network forms, technical and economic properties of the transport network, patterns of traffic flow and government policies in transportation.

Ramachandran (1974) has done work on the connectivity of network of Tamil Nadu state, where he discussed about the pattern of road connectivity.

Mukerji (1974), has made an attempt to correlate road connectivity and level of urbanization in Rajasthan by measuring structural properties of network at the district level. He has considered aggregated transport score (ATS) to identify the spatial inequalities to transport network development within the state and also highlighted the fact that, how the terrain variability and administrative preferences affects the level of urbanization and connectivity.

Ramachandran (1975), to measure the network geometry and relative cohesiveness of the transportation network different indices of connectivity such as alpha, pi, theta, eta, beta, iota, gamma, cylomatic number, and diameter have been used. According to him, these techniques of connectivity are used to compare the efficiency of transport network between the regions.

Saxena (1980), has examined the relationship of road connectivity of Rajasthan with the economic development of the state. In the year of 1983, the level of urbanization has been analysed in relation to the road transportation system of Rajasthan. He has considered only three basic measures i.e. beta, cyclomatic number and index of connectivity to

calculate road connectivity of the state at district level and obtained a composite connectivity score using z-score method.

Sekhar (1989) has worked on the analysis of road transport network in the drought prone area Anantapur District, Andhra Pradesh. The primary focus of the study was on the existing pattern, efficiency and flow of road network in the district. He has also attempted to find out the major problems of road network at a micro level. An analysis on the characteristics of existing road transport, their changing structural pattern and growth, degree of passenger floe, route efficiency; and nodal accessibility have also been considered. Sharma (1989) has also done a similar kind of study on the transport network of Manipur state.

A study related to the Spatio-temporal pattern of transport and communication system in Goa state was done by Badiger (1994). He mainly analyzed the characteristics of road transport, nature of traffic flow and problems related to transportation in Goa.

Bhaduri (1992), has analysed district level road transportation efficiency in West Bengal by measuring degree of connectivity. She has portrayed a detailed account on the historical development of the road network of the state from precolonial period to modern period. She has also considered the analysis of network pattern that was there during the study period. Later she has worked on the road safety (2007) across the country and the growth pattern of motor vehicles in six major cities of India (2008).

Down, A. (1992), has analysed the effects of adopting traffic congestion remedies such as raising gasoline taxes, construction of high capacity roads, better coordinating traffic lights. He has also provided a set of little-known principles of occurrence of traffic congestion. Author has formulated a law in 1962 by analysing traffic congestions of the world known as “Down’s law of peak hour expressway congestion” where explained the fact that, why creating more highway capacity cannot eliminate congestion, no matter how much capacity is added.

OECD (1999), have studied the traffic congestion in European countries. The main emphasis were given on the causes, volume and negative effect of traffic congestion. They have also stated some strategies for the reduction of congestion.

NCHRP (2001), Report 436 of National Cooperate Highway Research Programme of Transport Research Board (America) have stated the economic implications of congestion including user impacts of congestion, and non-users cost of congestion. They have also provided a framework for measuring the economic cost of congestion.

Down, A. (2004), has theoretically analysed the traffic congestion in his previous work in 1992 and added two important aspects in this volume i.e. the role of accidents and incidents in generating traffic congestion around the world. He has portrayed

fundamental nature and causes of congestion during peak-hour in the metropolitan cities. He has also proposed some measures to reduce congestions.

Tang and Waters (2005), have perceived that a nation's transportation system is crucial. The preferred nature of its transportation infrastructure has a significant impact on the economic and social health of a metropolitan area. Geographic Information System is emerging as a popular tool for transportation analysis as a result of advances in computer technology.

OECD, (2007), again on 2007 a study was made for managing urban traffic congestion and mapping the reliability of urban road system performances.

Rani (2009) has studied the development of road transport network structure and growth of urban centres in the Rohtak division of Haryana, where she tried to analyses the level of road transport development during 1971 to 2001 by considering the length of roads of various types in various years. She also analyzed the growth of urban centres along the major roads in the region and performed various network geometry analyses such as- connectivity index, nodal accessibility, and accessibility index.

Sweet (2011), has studied the economic value of congestion induced ravel delay. According to him, congestion slows down the metropolitan growth, inhibits agglomeration economies, and shapes economic geographies. He also has stated few public-sector congestion mitigation policies to reduce congestion.

Kharkongor (2012) has worked on the road network and socio-economic development in Ri-Bhoi District of Meghalaya where he has analyzed the road accessibility and demographic changes. He also emphasised the road influence of road networks on socio-economic development of the region in terms of literacy level, per capita income and accessibility to infrastructure and socio-economic status. Finally, he has done a detailed road impact assessment in the region.

Sen and Raman [2](2012), introduced intelligent transportation system for Indian cities. They have stated, Indian traffic can be benefited from several possible ITs applications for traffic management such as – intersection control, incident detection, vehicle classification, monitoring, revenue collection, and historical traffic data.

ITDP. (2013), have made an attempt to provide a vivid guideline to creating safe, and comfortable footpaths in the urban areas. According to them, continuity, comfort and safety are the major criterion for designing and constructing footpaths or sidewalks. They have categorised the footpaths into three main zones: the frontage zone or dead zone, the pedestrian zone, and the furniture zone. They have also provided guideline regarding footpath width in residential zone, commercial zone and high intensity commercial zones.

[2] https://www.usenix.org/system/files/conference/nsdr12/nsdr12-final2.pdf

Nakat, Herrera and Cherkaoui (2013) have stated, in the Cairo metropolitan area, traffic congestion is a major issue that has a negative impact on the area's quality of life as well as its economy. To assess the costs and factors contributing to congestion in the Greater Cairo Metropolitan Area, a study was launched (GCMA). The causes, types, and locations of congestion were determined in the first part of the study, which also evaluated the direct costs of congestion for the main corridors in the GCMA. The costs associated with traffic congestion, unreliable travel times, excessive fuel consumption, and CO2 emissions from moving cars were included in the definition of direct costs. Finally, a wide range of alternative policy initiatives are examined for their applicability and efficacy in resolving the GCMA's traffic congestion issues. Based on what has been done in other parts of the world and after speaking with important stakeholders who are knowledgeable with the traffic issues and conditions in the GCMA, the initial list of policy options was created. There are both "soft" measures (like enforcement) and "hard" actions on the list of available policy alternatives (new transport infrastructure).

Falcocchio and Levinson (2015) have explored the issue of road traffic congestion in cities and suburbs. They outline the issues, explain their sources, effects, and solutions. They initially focused on how congestion reflects changes in settlement patterns and transportation technologies.

In metropolitan India, high levels of air pollution from transportation systems represent a serious threat to public health. While there are still long-term obstacles to eliminating pollution sources, urgent action must be taken to reduce dangers to people that are exposed. (Lytton et al, 2016).

Sreelekha, Krishnamurthy, and Anjaneyulu (2016), have emphasized the interaction of road network connectivity and spatial pattern of the roads in Calicut city

He and Liu (2016), have studied the traffic congestion for the urban road network in Bejing based on the speed performance index.

In order to reduce traffic congestion, Raiyan (2017) developed a novel strategy for managing road traffic in smart cities. The method was built on a foundation of approaches for finding, updating, and allocating resources (SUA). It uses previous observations to find the shortest path, then generates real-time trip time estimates depending on vehicle location. The internet of things (IoT) and intelligent transportation system (ITS) technologies are also covered in the study.

According to Kumar and Singh (2017), building a new road or enlarging an existing one can ease traffic temporarily. Smart traffic control and information solutions are needed to combat the major issue of rising and current traffic difficulties in Indian cities, which can consequently minimise the traffic congestion and increase the demand for public transport.

Chauhan, Varshney and Saraswat (2017) have worked on the problems of road encroachment in Aligarh city and also provided some of the solutions to tackle the problem. Similar work also has been done by Singh (2018) in Ludhiana city, where he concentrated on the causes and types of road encroachment in the study area and also analysed the government rules and regulations related to the road encroachment.

According to Shafiei, Gu, and Saberi (2018), traffic congestion is considerably impeding global economic growth and development due to the record number of vehicles and network infrastructure complexity.

Metz (2018), perceived most credible approach to mitigate urban road traffic congestion by changing for road use from the experience of London, Stockholm, and Singapore.

Chakraborty (2019), has studied the present traffic condition of Siliguri city emphasizing the social and environmental consequences of traffic congestion.

Sengupta (2015), has studied the existing traffic problems and also proposed some remedies to solve problem

1.7 Research gap

There are very negligible number of research carried out on the transport network analysis of the Siliguri city based on geographical perspective. Academic research on structural properties, traffic flow analysis is yet to be explored extensively. There are only a few projects that have been carried out for the city like Siliguri Comprehensive Mobility Plan-2030 by SJDA (2013), City Development Plan for Siliguri-2041 of Capacity Building for Urban Development Project (2015), City Development Strategy for Siliguri-2011 by Department of Regional Planning (SPA), Rapid Baseline Assessment-Siliguri of Ministry of Urban Development and Draft Development Plan of Siliguri 2008-13 by Siliguri Municipal Corporation. These projects throw light only on the existing road conditions and development strategies.

1.8 Study area

The city of Siliguri (Fig. 1.4), located in the Darjeeling district has been selected to carry out the present study which is a geo-strategically significant city of Eastern India as it is bounded by national and international boundaries. A detailed account on the overview of study area is given in chapter 2.

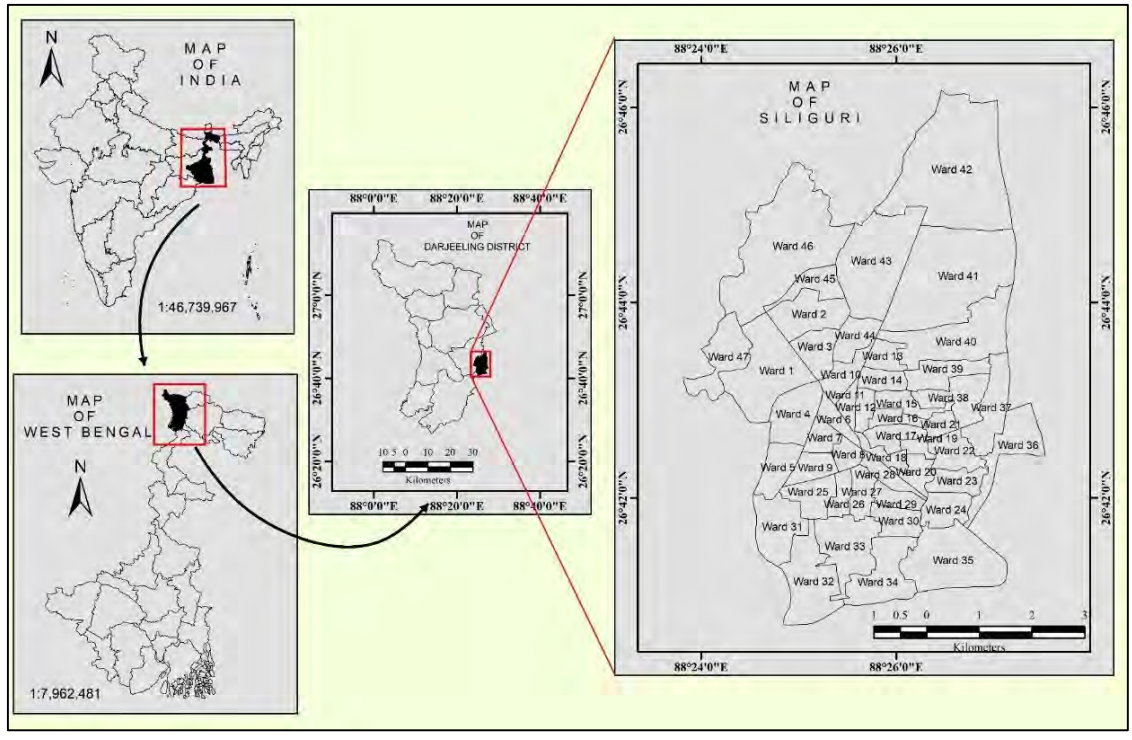

Fig. 1.4 Location map of the study area (base map sources: DIVA-GIS data, District Census Handbook, 2011 (Darjeeling), Siliguri Municipal Corporation**).**

1.9 Statement of the research problem

In Siliguri city, the transport system comprises roadways and railways, but roadways are the dominant mode of carrying a huge proportion of the traffic generated in the city. There is no option for rapid urban transport facilities like the metro and local trains. The opportunity to travel by train is negligible within the city. So the daily passengers are forced to travel by road transport only, which creates huge congestion within the city and ultimately affects the productivity of people and technology. The growth of urban centre in terms of human and vehicular population in Siliguri city comes with the difficulties to maintain even the least acceptable levels of urban services provided within the city. Transportation one of the basic urban services has deteriorated severely in recent times in Siliguri mainly due to the increased rate of usage of public and private transport leading to a huge load on the existing road network of the city. The structural properties of a transport system such as accessibility and connectivity of road network also play an important role in overall growth. Moreover, Siliguri as a city is unplanned. The haphazard road development of the city directly or indirectly affects the uneven vehicular flow and the entire urban outgrowth. Road transport of the city also has an impact on the economic and administrative centralization too. Under the circumstances, it has become a crucial aspect to the urban planners, policymakers and the geographers to study the entire urban road transportation system of the city in detail for making efficient and convenient decisions for the betterment of road transportation system.

1.10 Research hypotheses

Hypotheses are considered as the principal instrument of research functioning new experiments and observations through preliminary explanation and postulation. A hypothesis is an educated guess or prediction that can be tested in the future. Based on previous literature related to the topic and personal experiences of the researcher following hypotheses have been adopted for the present study:

i) On-street parking of vehicles are more in Siliguri city compared to off-street parking.
ii) The average travel time of the major roadways of Siliguri city varies on different days of the week and different hours of the day.
iii) There is a direct relationship between road network and the various service facilities of Siliguri city.

1.11 Objectives of the study

Research objectives summarize those specific goals of the researcher which are to be achieved by the study. The present study aims to find out the solutions to the problem mentioned above and the following research objectives have been considered for the specific purpose:

i) To study the characteristics of the major arterial roads of Siliguri city.
ii) To examine the degree of accessibility and connectivity of the major roadway network of the city.
iii) To analyse the traffic flow along the major arterial roads of Siliguri city.
iv) To assess the relationship between road transport and various service facilities of Siliguri city.

1.12 Materials and methods

Field study is an integral part of the research work, conducted to correlate the theoretical knowledge with the ground reality and to evaluate our understanding and explanation in the real world situation. Three-phased research have been carried out to fulfil the study objectives;

A. Input data, comprising data collection and preparation for the analysis
B. Analysis, involving the measurement of structural properties, spatial analysis of network and the generation of the maps using GIS, and
C. Reporting

1.12.1 Input data describes the procedure of collecting the information and analysis of the data based on;

Pre-fieldwork deals with the planning of the whole work, (Sarkar, 2009) such as, review of relevant literature, objectives setting, formulation of the hypotheses, finalization of the domains or parameters of the study and preparation or framing a comprehensive roster for the survey of commuters travel behaviour, travel speed survey, traffic volume survey and measurement of physical characteristics of road network.

The present study is confined to the road network analysis within Siliguri city marked by the area of Siliguri Municipal Corporation. A detailed analysis has been done to portray the whole existing road condition in the city. As the Chapter 3 and Chapter 5 is dealing with the general characteristics and traffic flow of the major arterial roads, the primary and foremost important task is to define the major arterial roads which are included in the study. On the basis of the traffic function and importance of the roads marked by the municipal authority, 12 major links of arterial roads (28.68 kilometres) have been considered (Table 3.2 and Fig. 3.1).

Selection criterion for the arterial roads

- Roads identified as arterials by Siliguri Jalpaiguri Development Authority (SJDA)
- Marked as important road by the municipal authority.
- Routes for long distance public and private funded Buses and Lorries.
- Pavement roads having carriageway of at least 7 metres.

Selection of nodes and links for graph theoretic measures

Whenever we study the structural properties of road network and associated development it is important to consider all the major roads including the arterials, sub-arterials and collector roads available within the study area. Thus, for the Chapter 4, major roadways of the city (28.68 kilometres of arterials, 20.85 kilometres of sub-arterials and 5.70 kilometres of other important collector roads) have been considered as defined by the municipal corporation. And for Chapter 6 all the roads (total 705.37 kilometres) including local roads have been considered.

In this phase, required secondary information and data have been collected from Basic Road Statistics of India for different years, National Highway Development Project, NITI Ayog, Census of India (1901-2011), Siliguri Municipal Corporation, Statistical Year Book of Ministry of Statistics and Programme Implementation, Public Work Department, and different published and unpublished sources like journal articles, books, magazines, newspaper reports, theses, and various reports of government and non-government agencies. First two chapters are entirely based on these secondary sources of information (Table 1.1). Whereas the chapters 4 and 6 are partially based on the data from secondary sources.

Table 1.1 Data sources for Chapter 1, Chapter 2, Chapter 4 and Chapter 6

Sl. No.	Data	Source
1.	Base maps of SMC	Siliguri Municipal Corporation, 2017
2.	Roadway map of SMC	Siliguri Municipal Corporation, 2017, OSM
3.	Length of major roadways	Primary survey, 2020
4	Length of water supply line	Siliguri Municipal Corporation, 2017
5.	Length of drains	Siliguri Municipal Corporation, 2017
6.	Location of urban services	Primary survey, 2020

Source: Compiled by the researcher

Chapter 4: Both the primary and secondary data have been used in the Chapter 4. Road network connectivity and accessibility is analysed based on the road map collected from municipal authority and extracted from Open Series Map (OSM). All the selected nodes or junctions and the roads i.e. arterial, sub-arterial and few important collector roads are digitised on ArcGIS 10.5 platform to perform the analysis. Length of the major road network have been measured using digital odometer.

Chapter 6: This is based on both the primary and secondary data and information. The ward-wise road lengths were obtained from municipal office (Table 1.1). Ward-wise location of the selected urban service facilities were recorded using a handheld GPS (Table 1.2). For the length of drain system and waterlines, base map were collected from the municipal authority (Table 1.1). Maps were processed and digitized using ArcGIS 10.5 platform to calculate the lengths of drain and waterline for each wards of Siliguri.

Fieldwork: This subsection includes the collection of primary data through field visits, recording of different traffic control point locations, traffic volume count, recording of time and distance covered by travelling using Global Positioning System (GPS) to calculate average travel speed of vehicles. To collect the primary data and information a cross-sectional study has been carried out in the study area. Primary data have been used in Chapter 3 and 5. Detailed methodology and data sources have been discussed in the following sections.

Chapter 3: An important element of basic data of transport system is the survey of existing transport facilities obtained from surveys of the road network, public transport facilities and parking provisions (Roberts, 1974). In the study area, all the physical and functional characteristics of major road transport network are collected through field measurements, counting and observations. Road length is measured using digital odometer whereas the width of carriageway, width of footpath, kerb height, and shoulder width are measured using measuring tape. Information about the number of lanes, encroachment of road and footpaths, parking provision, number of street lights, status of traffic signals and the number of passes/gaps along the median or central reservation are collected through filed observation and counting method. All the data were collected using Worksheet 1 (Appendix I). A travel speed survey was conducted on all the sections of major road network of Siliguri including the arterial roads. Travel speed observation were made by driving a test vehicle (two wheeler) without overtaking forward vehicles

on the road. It was also ensured that the test vehicle travel at an average speed of 40 kilometres per hour during free flow section. A total of 35 surveyors were assigned to record travel time data in all the selected road sections. Data were collected for 24 hours at 1 hour time interval for 4 days i.e. Monday and Friday to calculate average travel time on weekday and Saturday-Sunday data for calculating average travel speed on weekends. Post which all the data were analysed according to measure the level of congestion using the methods mentioned in Section 3.6.

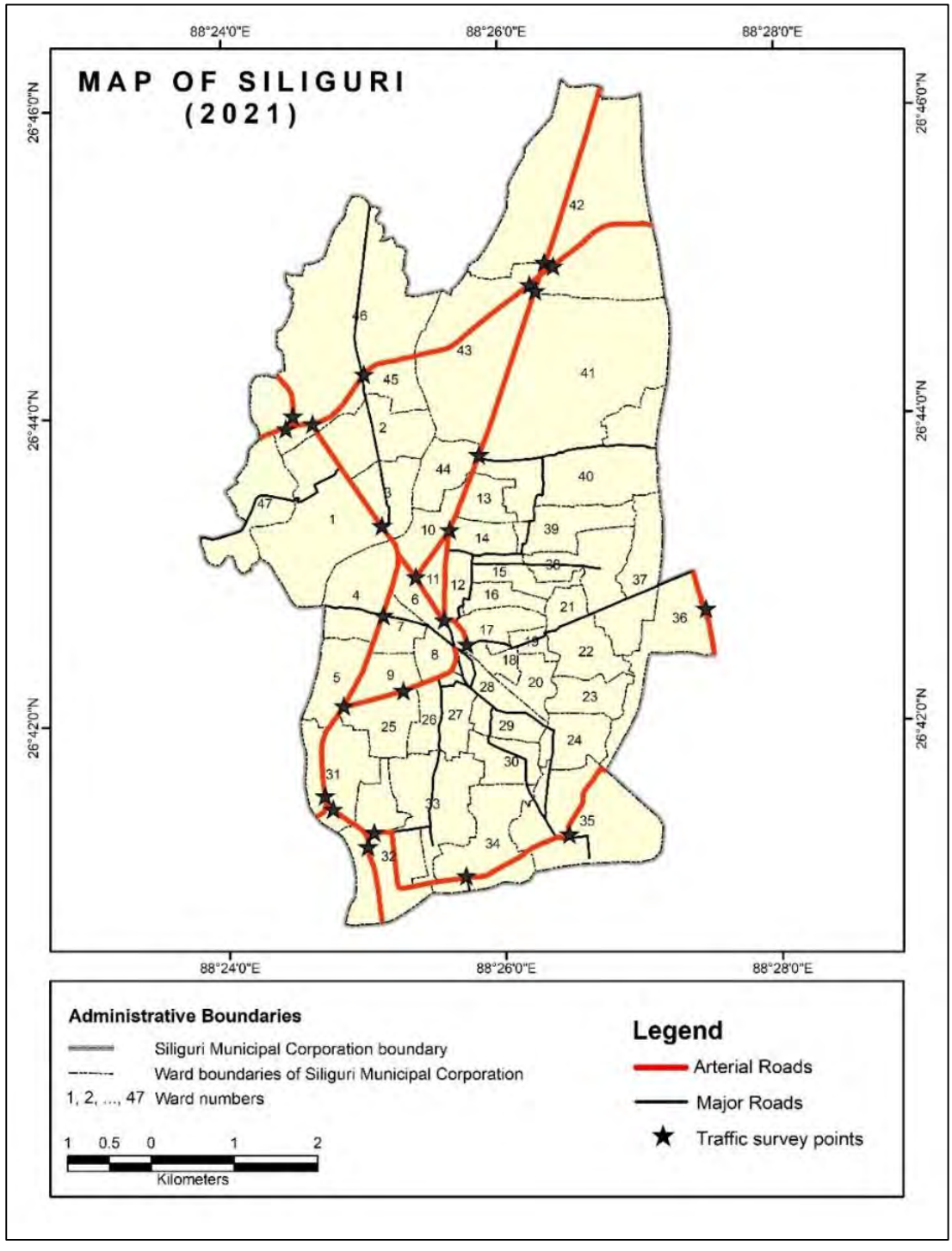

Fig. 1.5 Locations of the traffic survey points along the arterial roads of Siliguri

Table 1.2 Data sources for Chapter 3 and Chapter 5

Sl. No.	Data	Source
1.	General characteristics of roads	Primary survey, 2021
2.	Average travel speed survey	Primary survey, 2021
3.	Traffic volume count	Primary survey, 2021

Source: Compiled by the researcher

Chapter 5: To ascertain the actual developmental requirements of a road system, traffic surveys are necessary. The amount of road traffic that needs to be accommodated in any plans, arrangements, or designs for road development depends on the current or anticipated volume of traffic. Traffic surveys offer a method for reasonably accurate estimation of the volume of traffic on the roads. For various purposes, different amounts of data and different types of surveys are needed (GoD, 2014). Traffic volume, composition and fluctuation analysis is done based on the traffic volume count survey along the arterial roads of the city. For the survey, all the sections of twelve arterial roads are divided into twenty four sub-sections and numbered accordingly. Total twenty four surveyors were assigned at same time for each and every sub-section of arterial road with digital camera to record traffic volume (Fig. 1.5). Video recordings were taken for four days and three times per day to record average count of vehicles i.e. morning peak hours (10:00 am to 11:00 am), lean hour (2:00 pm to 3:00 pm) and evening peak hour (6:00 pm to 7:00 pm). Post which, all the videos were used for classification and count of vehicles as per the Worksheet 2 (Appendix II). For this chapter a passengers' survey have also been done with a set of semi structured questions in second phase of survey. Total 300 passengers' and daily commuters have participated during the phase of survey (Worksheet 3 of Appendix II).

1.12.2 Analysis

In this section, post fieldwork or data processing and analysis by classification, tabulation of collected data, data presentation and testing of hypotheses have been done. Measurement of structural properties using different connectivity and accessibility indices (Eq. 4.1 to Eq. 4.8), spatial analysis of road network and the generation of the maps using GIS have also been done in this section.

Chapter 2: Some descriptive statistics, percentage analysis and cartogram techniques have been used in the second chapter.

Chapter 3: Suitable maps, cartograms, descriptive statistics and percentage analysis are used in this section to depict the physical and functional characteristic of the major road network of Siliguri city. For the analysis of level of congestion along the arterial roads different techniques have been adopted such as segment delay, delay rate, relative delay rate, delay ratio, average travel speed and traffic density. Average travel speed refers to the ratio between total travelled distance in kilometres and total travel time in hour. Whereas, the traffic density refers to the ratio of total number of vehicles and length of road section in kilometres. Delay rate is a measure for the estimation of differences

between transportation system performance and expectations for those system elements. Whereas the measure of relative delay rate is used to make a comparison between relative congestion on roads and different mobility standards for the system elements like arterial, sub-arterials and other transit routes (Lomax et al, 1997; Aftabuzzaman, 2007). Relative delay rate also shows the flow condition, which is relatable to the travel experiences of the travellers (Hamad and Kikuchi, 2002) and the delay ratio is use to make a comparison with the relative congestion levels on the public transport routes (Lomax et al, 1997; Aftabuzzaman, 2007). To validate the first hypothesis related to parking conditions of Siliguri city, principle of difference and Wilcoxon signed rank test has been performed using SPSS 25 Trial Edition. For checking the normality of distribution, Kolmogorov-Smirnov and Shapiro-Wilk methods have been considered using SPSS 25 Trial Edition (Fig. 1.6)

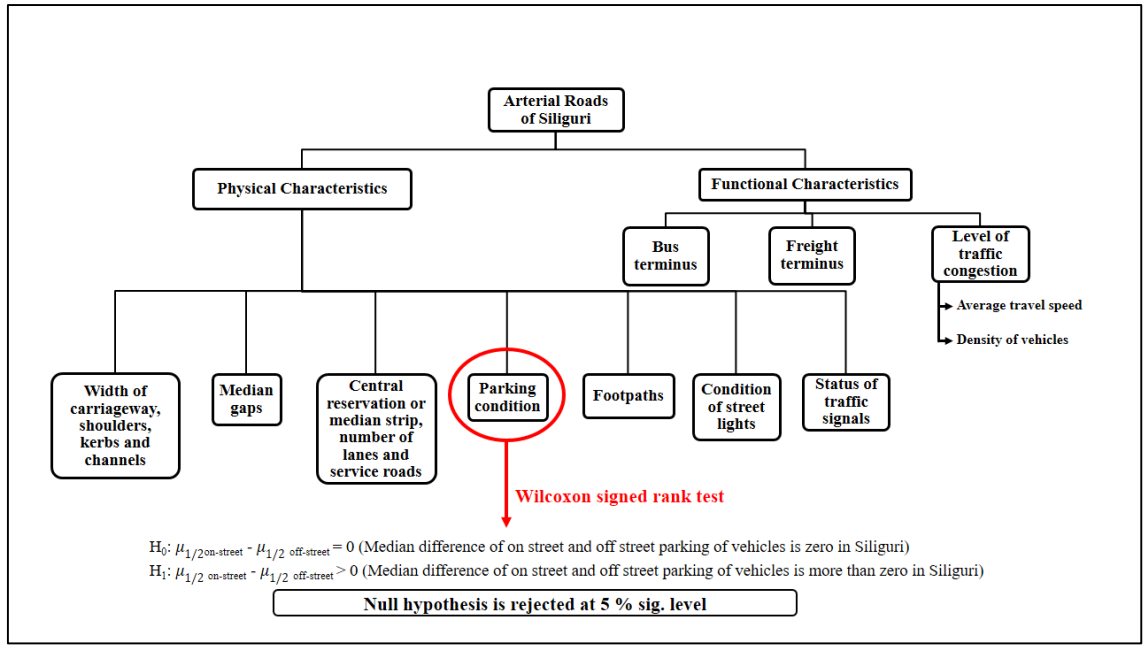

Fig. 1.6 Adopted methods for analysing the general characteristic of arterial roads

Chapter 4: In order to provide a better understanding, evaluation and basis for comparison of networks through the analysis of structural properties and intersection pattern of road network cartographic and graph theoretic measures are imperative in geographical research. Physical accessibility of road have been calculated by multiple buffer analysis using geo-processing tool of ArcGIS 10.5. Along with that, different graph theoretic measures and statistics are used in this section to analyse the connectivity and accessibility pattern in the city.

Chapter 5: Traffic flow map, Passenger Car Unit (PCU) analysis, vehicle density analysis and descriptive statistics is used for the analysis data in this chapter. Whereas, for the validation of second hypothesis Analysis of variance (ANOVA-Single factor) is used.

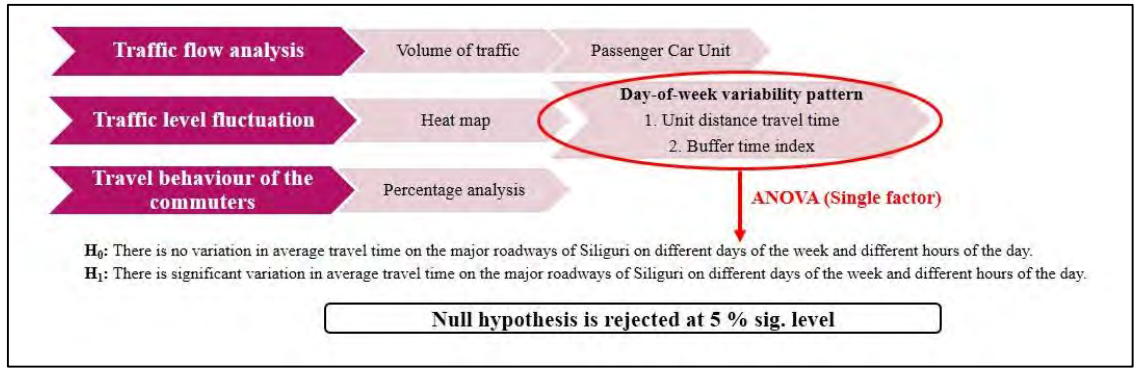

Fig. 1.7 Adopted methods for analysing the traffic flow and variability pattern

Chapter 6: To depict the spatial variation of road network and its relationship with various urban services of Siliguri following statistical analysis (Eq. 6.1 to 6.5) have been carried out using Microsoft Excel Spreadsheet 2013, SPSS 25 Trial Edition.

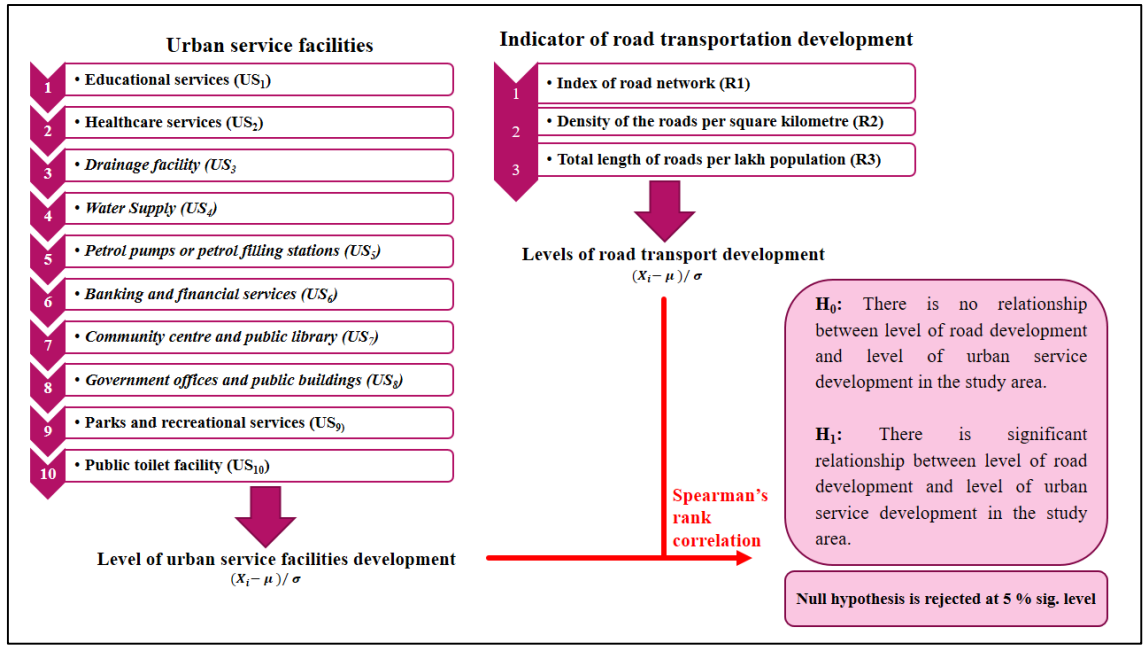

Fig. 1.8 Adopted methods for analysing the road transportation development and urban service facilities

Along with the above-mentioned methods, third hypothesis is validated using Spearman's rank correlation technique. Different cartograms and thematic maps have also been used to portray the array of information.

The entire methodology involves the application of Geographic Information System to evaluate the road network of Siliguri city. As already mentioned earlier, the city road system including arterial, sub-arterial, collector and local streets have been extracted from Open Street Map and Transportation Map collected from Siliguri Municipal Corporation Authority. The authority also has provided an AutoCAD drawing file, from where all the other necessary information have been extracted such as ward boundary, location of educational institutions, location of government offices, drainage length, location of

community centres and toilets, location of health clinics, parks, recreation centres, places of worship, tube wells and taps. To obtain these information from the drawing file, AutoCAD 2019 Student edition has been used.

1.12.3 Reporting

Finally, in the last section interpretation of data and report have been done using MS Word 2013. For the referencing and citation JabRef and Mendeley software have been used.

1.13 Significance of the study

The transport system of any region is the key factor in location and growth of the cities. It is a strategic infrastructure that is embedded in the socio-economic life, industrial, institutional and corporation that is often invisible to the consumer. An adequate and efficient transportation facility for both the passengers and goods is the most essential requirement of city life. Because the cities generally grow around the nodes and break of bulk points of any transportation system. But an unorganised and haphazard network of transportation may lead to many obstacles in the overall development of the city and wellbeing of the city dwellers. The present study describes the general overview of transport network of Siliguri city including the assessment of accessibility and connectivity of major nodes, physical condition of the existing road network within the city, traffic flow, peak-hours congestion and illegal encroachments. The study also analyses the impact of urban road transport network in the developmental process of the city (level of urban service development).

Siliguri needs an urgent attention towards its urban road and traffic management, as the city has already started facing intensive and long traffic jams at major traffic points which has increased the average travel time manifold within few years. It is already mentioned earlier that, the present study falls in the purview of transportation geography. However, in broad conformity it also touches with urban geography, economic geography and regional planning. The study objective not only includes the geographical perspective of the road transport system but also includes the overall developmental perspective by analysing the relationship between road development and urban services. The study also tend to provide some recommendations and suggestion to overcome traffic problem of Siliguri in scientific manner and way to achieve a balanced and less congested roadways. Thus, the study is very significant for the selected study area.

1.14 Scope for further research and limitations

The impact of road transportation system on the socio-economic condition, physical environment and health of city dwellers have not been considered in the present study which could be a great topic of exploration in urban road transport network analysis. The present study is solely dealing with the road transportation analysis, railway network has

not been considered. Although, railway network is not prominent as roadways in Siliguri, economic and social aspects of railway network could be a good area of geographical research in Siliguri and its surrounding region.

In order to get a better control over the quality of the data, traffic surveys for the current study were conducted utilizing video cameras and processed by the researcher in a controlled office environment. However, the cost-effectiveness of this approach is limited. For an individual researcher, conducting such surveys and processing the enormous survey data is highly expensive, time-consuming, and very difficult to handle. There are numerous types of automatic traffic counters, including radar, infrared, pneumatic tubes, and piezo-electric counters. But the researcher was unable to use those devices and instruments due to the high price and unavailability. Unfavourable weather conditions such as high temperature and rain were also an issue while collecting the primary data especially during afternoon period.

1.15 Concluding remarks

It is evident from the fact that all megacities, cities, towns, and district headquarters having good connections to their surroundings are the most developed, as the transportation network connects different places that help with the overall growth of any place. Significant reforms in the transportation sector are necessary for the region's continuing economic progress. Siliguri, having a nearly flat topography is very favourable for the development of an efficient road transportation network. . But the spatial arrangement, physical condition and poor traffic management on the roads are responsible for haphazard and congested road transportation system. A detailed account on the road transportation of Siliguri has been dealt in the following chapters.

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