HIGHWAY DRAINAGE MAINTENANCE AND SAFETY: A CASE STUDY

by
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CERTIFICATE

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CANDIDATE DECLARATION

I **Pratap Singh** declare that this thesis titled **Highway Drainage Maintenance and Safety: A Case Study.** And the work presented in it is my own. The work has been carried out under the supervision of **Dr. Mahender Choudhary** and **Prof. Sudhir Kumar**, Civil Engineering, Malaviya National Institute of Technology. Jaipur. I confirm that:

1. The work has been accomplished for a Ph.D. degree at MNIT Jaipur.
2. Any part of this thesis has not been submitted earlier for any degree or any other purpose at MNIT Jaipur or any other institution.
3. A number of published works has been read and quoted to make it imperical work.
4. It is acknowledged that inferences are made upon the available research in the area and a new angle is delineated.
5. It is an original work without any plagiarism at the level of language as well as content.
6. I have acknowledge all main source of help.

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This is to certify that the above statement made by the candidate is true to the best of my knowledge.

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(Pratap Singh)

ABSTRACT

Numerous studies have been done on various components of highways roads in other countries yet very few are available in the case of India. Particularly, on the road work, maintenance and drainage system there are no sound report as in Rajasthan has not been given much importance due to deep water table conditions and large filtration through soil depth. Pavement design, conditions, parameter of future pavement deterioration, vehicle operation cost and safety are also need to be considered in India. The conditions of suitable traffic variation, weather, proper drainage system also required to be considered in highway project as well.

The analysis of primary and secondary data regarding highway drainage, damaged due to rains, maintenance and safety with traffic are conducted by modular regression method. The conclusions are achieved by narrating rainfall moderately related with road accident. Due to poor drainage the maintenance cost increases, and safety also has a direct and positive relationship with maintenance cost. The find survey validation with data concludes that dividers on highways need to be designed so that rain water near curves is collected by installing water storage tanks in divider instead of disposing in cross drainage. The pavement surface water further may be utilized for tree plantation. The raised divider with plantation improves road safety as well. Continuous row of tree plantation also improve road safety by reducing glaring effect during night time.

The result obtained from find survey data collection, poor drainage system, lack of future maintenance conditions ultimately increase vehicle operation cost and travel time. On reviewing research studies conducted on recent highway drainage conditions, it was found that during planning and construction of highway, no proper attention is being paid towards future maintenance of pavement and drainage system. It is observed that most of the highways and busy roads during perception survey found damaged during rainy session carrying high traffic intensity and more water retention time on pavement surface. It was found in the perception data analysis that in spite of carrying more traffic if water retention time on pavement surface minimized by providing water storage tank and using it for harvesting at suitable places then a huge amount of future maintenance cost can be saved.

The respondent of find perception revealed that for optimum maintenance, camber correction and sealing of pavement surface before monsoon will reduce development of potholes, patches, ruts and other cracks thereby increasing safety and improving vehicle operating cost with travel time. This will also eliminate the problem of ultimate disposal of road side drains into cross drainage which are usually encroached due to ribbon development along highway roads.

The perception analysis concludes that the improvement proposal of widening highway road should include the cost of storage of rain water for tree plantation. It also includes recharging ground water to reduce maintenance of highway road, vehicle operation cost, travel time along with conservation of water. The ultimate project will improve greenery in arid and semi-arid areas.

The findings have given importance to the role of drainage system with maintenance factors and factors for improvement in the design system. The maintenance of highways needs routine and periodic maintenance, rehabilitation and strengthening. In the maintenance part, regular evaluation is also required to assess the present condition of highway roads. The study of maintenance systems shows that drainage and surface defects are some important factors, which need special attention, apart from prevent moisture in pavement design. Kendall's correlation result and factor analysis of research data give important factors as the highway drainage with genuine maintenance and safety aspect which are essential features needed to be considered in modular highway design system. The secondary data analysis of variance concludes that number of accident have significant positive relationships with number of vehicles containing t-value (+7.08). The number of accidents has significantly negative relationship with maintenance cost containing t-value (-4.475).

Further number of accidents also has moderately positive significant relationship with rainfall with the t-value (+1.164). This research hence attempts to look at the various problems inherent in the construction of highways and recommends practical measures to tackle the same. Conclusively, a better drainage system at the level of planning, responsibility of multiple stakeholders including drivers and engineers, and regular maintenance of highways have emerged to be the focal points of a safe and smooth highway traffic movement.

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ABBREVIATIONS

ACAS	=	Accident Caution Analyses System
ANOVA	=	Analysis of Variance
ATB	=	Asphalt Treated Base
BD	=	Blackish Deposit
BOT	=	Built Operate Transfer
CRRI	=	Central Road Research Institute
CRWR	=	Centre for Research in Water Resources
CTB	=	Concrete Treated Base
DBFOT	=	Design Built Finance Operate Transfer
DOT	=	Department of Transportation
FHWA	=	Federal Highway Administration
GDP	=	Gross Domestic Product
GDP	=	Gross Domestic Product
GIDAS	=	German in Depth Accident Study
GIS	=	Geographic Information System
GPR	=	Ground Penetrating Radar
GSDP	=	Gross State Domestic Product
GT	=	Grand Truck
HDM	=	Highway Design Model
HMA	=	Hot Mix Plant
IRC	=	Indian Road Congress
JDA	=	Jaipur Development Authority
MDR	=	Major District Road
MORTH	=	Ministry of Rural Transport & Highway
MOST	=	Ministry of Surface Transport
MSE	=	Residual Mean Square
MSR	=	Regression Mean Square
NGO	=	Non Government Organization
NH	=	National Highway
NH	=	National Highways
NHAI	=	National Highway Authority of India

NHARSS	=	National Hillway Accident Relief Service Scheme
NHDP	=	National Highway Development Project
NRS	=	National Road Statistics
NRSC	=	National Road Safety Council
OS	=	Original Surface
%	=	Percentage
PC	=	Pavement Cost
PCC	=	Pre-stress Cement Concrete
PMGSY	=	Pradhan Mantri Gram Sadak Yojana
PPP	=	Public Private Partnership
PR	=	Project Road
PSU	=	Payment Serviceability Unit
PUP	=	Passenger Under Pass
PVC	=	Poly Vinyl Chloride
PWD	=	Public Works Department
RLEGP	=	Rural Labour Employment Guarantee Programme
ROW	=	Right of Way
RR	=	Rural Road
RSA	=	Road Safety Audit
RSRTC	=	Rajasthan State Road Transport Corporation
SH	=	State Highway
SH	=	State Highway
SPSS	=	Statistical Package for the Social Sciences
SRF	=	State Road Fund
UK	=	United Kingdom
US	=	United States
USA	=	United States of America
VOC	=	Vehicle Operation Cost
VUP	=	Vehicle Under Pass
WHO	=	World Health Organization

CHAPTER 1

INTRODUCTION

A proper transportation system is vital for a country's economic development, trade and social integration. A road network system, in particular, is one of the most prominent means of transport in most countries. Its demand has been growing rapidly with increasing population and transport vehicles (MORTH 2012), particularly in developing countries, such as India, despite considerable barriers to interstate freight and passenger movement. The easy accessibility, flexibility of operations, door-to-door services and reliability has eased road transport. An increasingly higher share of both passenger (87%) and freight traffic (61%) are compared to other modes of transport in India (NHAI 2012). In road transport, national highways (NHs) play a major role in India because these road networks are the busiest networks in the world. According to reports, NHs constituted 2% of all roads in India handling 40% of the total road traffic in 2012 (MORTH 2012; NHAI 2012).

NHs are the lifeline of a nation and facilitate smooth conveyance of both people and goods within a country. NH roads require proper planning, designing and regular and proper maintenance for safe functioning. NHs are severely affected by rains and overflowing drain water, leading to huge direct losses in the form of maintenance cost to the national government and indirect losses to the people or society in terms of time, safety and vehicle operating cost (VOC). Recently, ribbon development has resulted in a poor drainage system, which is one of the main factors for damages on highways (MORTH 2012). It results in high maintenance cost and increased number of accidents with an estimated 2%–3% reduction in the national income or gross domestic product (GDP) (MORTH 2013). Furthermore, other factors such as poor climatic conditions, use of substandard material in roads, poor visibility at night and the absence of street lights necessitate highway maintenance and safety (MORD 2012).

Studies related to maintenance of NHs, particularly those on proper drainage systems and safety, have not been given due importance in India. Most of the damage to NHs is caused in rainy seasons, when water flows from adjacent areas on to the NH because of ribbon development and remain for longer periods on the Right-of-Way (ROW). Chapter 4 discusses that the absence of proper drainage or poor maintenance of existing drainages causes water to flow on pavements' surface and across the areas of ROW. The result may be anything from a trickle or a torrent of water running on or across the highway. Therefore, appropriate measures are required to ensure that an adequate drainage system is in place to prevent the occurrence of such hazards. Provision of an adequate drainage system is necessary for the highways in India, for which the existing highway designs must be investigated thoroughly, by considering drainage systems and other important factors (MORTH 2013; NHAI 2012). Such a study might designing of a highway network with a proper drainage system. In addition, it facilitates building an efficient NH network system in the country. Thus this study is an attempt to understand the aforementioned problem through a detailed investigation of existing NHs and provide appropriate suggestions for future. In the present study, the present condition of India's road transport and associated problems are discussed, followed by literature review existing literature, gaps, objectives, hypothesis, research methodology and results and discussions including theoretical considerations to draw further conclusions.

1.1 BACKGROUND

The road system connects different parts of the country to each other for better transportation. In India, NHs are maintained under the (NHDP); however, other road projects such as the Pradhan Mantri Gramn Sadak Yojna (PMGSY), National Rural Employment Guarantee Programme and Bharat Nirman are launched by the Government of India for road construction (MORD 2013). Every year, the government invests considerably for the development of new roads. However, improper maintenance and inadequate drainage invariably result in the short life of roads and an increased annual cost of maintenance (Mazumdar 2012). According to some studies, the cost of drainage and maintenance of roads varies from 1% to 2% of the total cost of roads (NHAI 2012). Most often, the planning, design and execution of road drainage systems has not been given due importance unlike structural and foundational design or construction of roads and highways.

Many concerns related to roads, particularly the safety and maintenance of NHs, exist. The lane capacity of Indian highways is very low: most NHs are made of two or less lanes. A quarter of all India's highways are congested and many roads are of poor riding quality; limited funds are provided for road maintenance and only one-third of maintenance needs are met. This causes deterioration of roads and high transport costs (World Bank 2012; WHO 2010). Highways require modernization to handle increased traffic requirements. In addition to maintenance, the expansion of the network and widening of existing roads are becoming increasingly important. This would enable the roads to handle increasing traffic and increase the average movement speed on Indian roads.

1.2 ROAD TRANSPORT SYSTEM IN INDIA

The subsequent sections highlight the present road transport system in India and provide its comparison with international systems. In addition, this research underlines the need for highway drainage improvement for maintenance and safety. Understanding the operation, transport, planning, design, safety and state government practices is also essential for summarising with field data results of the research. Figure 1.1 illustrates the road map of India with the NHDP . During independence in 1947, India inherited a poor road infrastructure. However, even after independence, between 1947 and 1988, India witnessed no major road projects. Predominantly, all the roads were single lane and mostly unpaved with no expressways, with less than 200 km of 4-lane highways. Road development started only after economic liberalisation in 1990s; subsequently, privatisation of road network development along with government schemes accelerated road construction.

Table 1.1 presents the comparison of the surfaced and total road length in the development period. The surfaced road length accounted for more than half of the total road length in 2011 compared with 39% of the total road length in 1951. The total road length has been expanded significantly since the 1970s. It has increased from 915,000 km in March 1971 to 4,690,000 km in 2011, an increase of 534% over 40 years, yielding a compound annual growth rate (CAGR) of 4.7%. The total road network in the country grew from 3,622,000 km in 2004 to 4,690,000 km in 2011, reflecting an increase of 413% and yielding a CAGR of 4.2% (MORTH 2013).

Table-1.1. Road Length in India

Year	Surfaced Roads (in thousand)	Total Road Length (in thousand)
1951	157	399
1971	398	915
2004	1761	3622
2008	2036	4110
2011	2535	4690

Figure 1.1 depicts the increase in Indian road length from 1951 to 2011 caused by these efforts. The total road length reflects more than 11-fold increase from 1951 (399,000 km) to 2011 (4,690,000 km). In addition, the surfaced road increased approximately 16 times from 157,000 km in 1951 to 2,525,000 km in 2011.

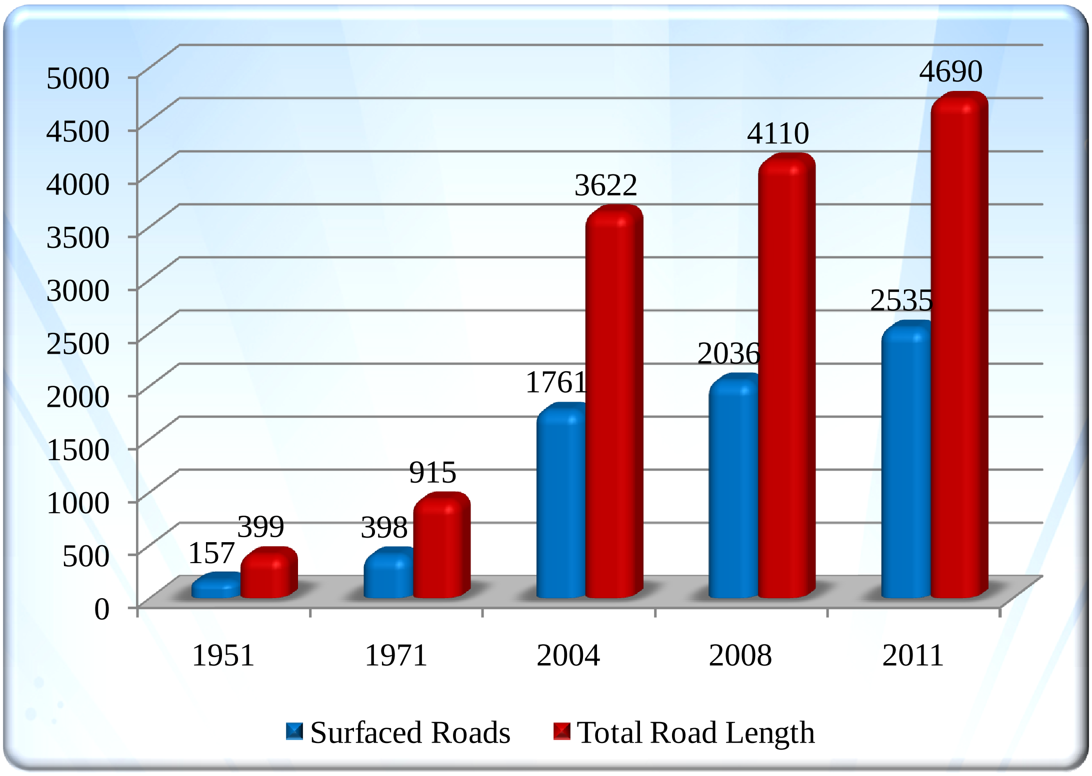


Figure 1.1. Road and Surfaced Length (in 1000 km) in India in 1951, 1971, 2004, 2008 and 2011

1.2.1. Road Classification

The Indian road network can be broadly classified into the following:

- National highways (NHs)
- State highways (SHs) and other public work department (PWD)roads
- Rural roads (RRs)
- Project and urban roads (PRs and URs)

The distribution of road length and its share in the total road length is shown in Table 1.2 (NHAI 2012). In 1988, the National Highways Authority of India (NHAI) was established by an Act of Parliament and came into power on 15th June, 1989. The NHAI Act, 1998 became operational with a mandate to develop, maintain and manage NHs. Although the authority was created in 1988, not much was done until the widespread economic liberalisation in the early 1990s (NHAI 2012). NHAI also collects fees on NHs and facilitates private sector participation**.** Since 1995, the authority has privatised road network development in India and by the end of 2011, it delivered over 71,000 km of NHs including 4- or 6-lane modern highways (NHAI 2013; PWD 2013).

Table 1.2. Category-Wise Road Length in India

Year	NH (km)	SH (km)	RR (km)	UR (km)	PR (km)
1951	20,000	1,74,000	2,06,000	0,000	0,000
1991	34,000	6,36,000	12,60,000	186,000	209,000
2011	71,000	11,68,000	27,49,000	411,000	288,000

Table 1.2 presents the category-wise development of road length in India in 1951–2011. NHs are the most essential for surface transportation in India and run across the country with a length of 71,000 km by the end of March 2011 (MORTH 2012). In 1951, the NHs comprised 5% of the total road network, but reduced to

approximately 2% in 2011. However, the length of NHs has increased by >3.5 fold during the same period (i.e, from 20,000 km in 1951 to 71,000 km in 2011). NHs are important because of their carry high capacity, that is, 40% of the total volume of road traffic in India (NHAI 2012).

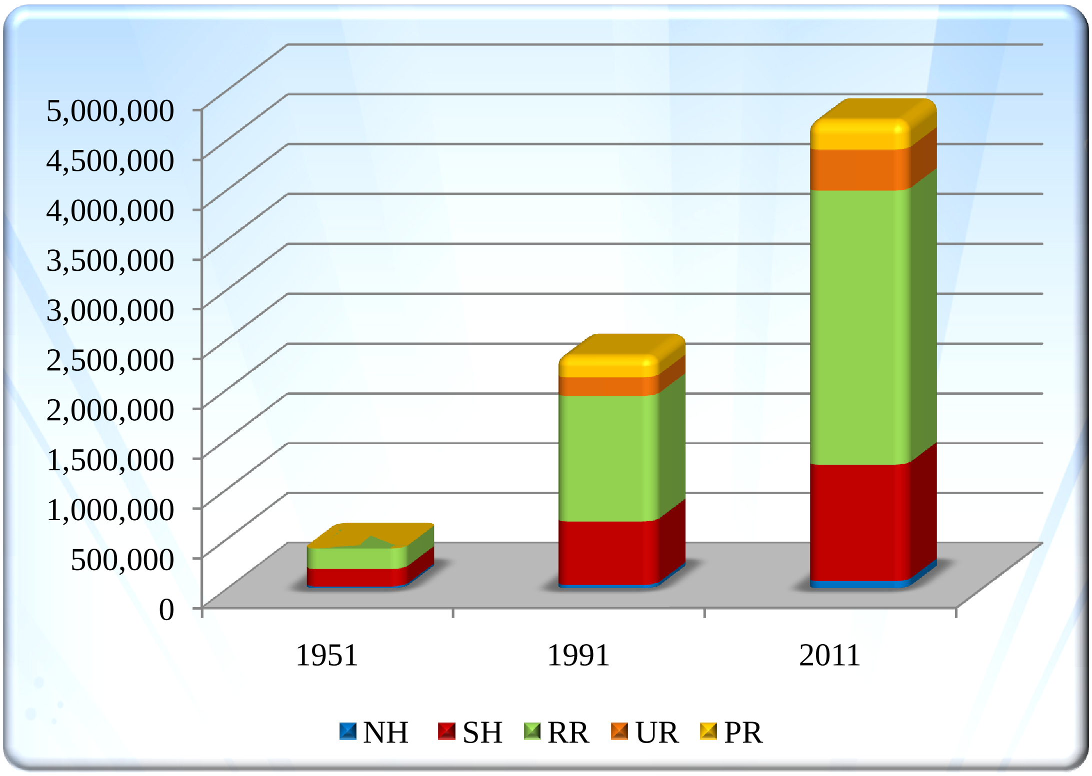


Figure 1.2 Category-Wise Road Length Share in Total Roads (in %) for 1951−2011

Figure 1.2 presents the comparative development of the road sector after independence. Major concerns associated with maintenance, safety and ribbon development along the highways arose because of the rapid development.

Apart from national highway, the other category roads are as follows:

(i) SH and Major District Roads

(ii) Rural and Ordinary District Roads

(iii) URs and PRs

The state PWD roads connect SHs with internal roads. The total length of SHs and other PWD roads was approximately 1,168,000 km in 2011. The SHs and PWD roads increased >6-fold from 1951 to 2011; they were 174,000 km in 1951 and increased to 1,168,000 km in 2011. Theycomprised one-quarter of the total road network in India. However, the share of SHs and PWD roads declined from 44% to 25% during 1951 to 2011. (MORTH 2012).

Rural roads have registered the high growth, approximately 13-fold, over the last 60 years mainly because of state and central government schemes (i.e from 206,000 km in 1951 to 2,749,000 km in 2011). The rural roads comprised more than half of the total road length in India in 2008; which increased from 52% in 1951 to 59% in 2008 (MORD2012). The length of URs and PRs was 411,000 and 288 km, respectively, in 2011. URs increased 6-fold from 72,000 km in 1971 to 411,000, while PRs increased approximately >2 times from 131,000 km in 1971 to 288,000 km in 2011. However, the share of URs increased marginally from 8% in 1971 to 9% in 2011. By contrast, PRs share reduced from 14% to 6% during the same period. (MORTH 2012; MORD, 2012).

Figure 1.3. Road Map of India representing NHDP

1.2.2 NHDP Scheme

To expand and improve road connectivity in the country, the Government launched the NHDP, which is presented in Figure 1.3. It is the largest highway project ever undertaken in the country. The NHDP, implemented by Indian government, has envisaged huge investment for construction and upgradation of NHs through various phases of NHDP over the midterm. As of June 2012, under phase I, II, III and V of India's national effort were completed and put to use approximately 18,000 km of 4–6 lane highways (MORTH 2012). The country is in the process of building an additional 33,441 km of 4-to-6-lane highways, international quality highways throughout India. This target, approximately 13,700 km of modern highways were under implementation in June 2012 and approximately 18,000 km of highways have been identified for contracts. The Indian highway road development rate has accelerated recently and averaged approximately 11 km per day in the second half of 2011. Figure 1.3 presents the categorised comparison of road length in India during 1951 –2011. NHDP aims to build 600 km of modern roads every month and 4- or 6-lane highways connecting its major manufacturing, commercial and cultural centres (NHAI 2012).

1.2.3 International Comparison

Table 1.3 presents a comparison of road densities per square kilometre of land between India and other developed and developing countries (Basic Roads Statistics 2012). India has the second largest road network in the world and 1.4 km of roads per square kilometre of land. The road network of India is similar to that of United Kingdom and France. Furthermore, the network is larger than that in the United States and is much larger than that in China and Brazil. However, qualitatively, India’s roads are a mix of modern highways and narrow, unpaved roads, with poor maintenance. Hence, proper maintenance of road pavement with a suitable drainage system on highway roads is required. (MORTH 2012).

Table 1.3. International Road Density and Percentage of NH in the total road

	Road Density per (Sq.Km. Road Network)	NH (% of Total Road)
USA	0.7	4.1
UK	1.7	11.7
Russia	0.1	-
France	1.7	1.0
China	0.4	1.3
Brazil	0.2	5.3
S Africa	0.3	0.8
Japan	3.2	4.5
Korea	4.0	13.5
India	1.4	2.0

1.3 HIGHWAY DRAINAGE

Pavement surface drainage is one of the important features of the present research. Previous studies investigated the aggregate performance deals only with load supporting capabilities. Literature reviews showed that the presence of water on the pavement is an important aspect of design. A good design must satisfy the condition of interception and evacuation of flowing water on pavements. This is mainly considered a requirement for a proper drainage and maintenance system. An adequate drainage is a primary requirement for maintaining the structural soundness, functioning and efficiency of a road. Pavement structures including sub-grade roads must be protected from all types of running water, which may weaken the sub-grade by saturation and cause distress in the pavements' structure (Cedergren 1974). The basic consideration of any road design is dispersal of water from pavements and sub-grade. The quick drainage removes water from the pavements' surface and reduces chances of damages to NH. Because of an inadequate drainage surface, a pavement structure is undermined by (i) causes of weakening of the pavement structure and sub-grade through infiltration of water from the top and (ii) erosion of shoulders, verges and embankment slopes caused by water running off the pavement (IRC-SP-42, 2004).

1.4 HIGHWAY MAINTENANCE

Highway road maintenance is an important activity, that needs to be performed by every highway department. The safety and convenience of using roads are governed to a large extent by the quality of maintenance. The operation economics of road transport is influenced by the degree of maintenance imparted to the road. The life of an asset can be preserved and prolonged, if adequate maintenance measures are undertaken in a timely manner. In developing countries, pavement thickness and lower specifications because of budget require a complete design to achieve economy of highway projects. Therefore, the proper maintenance of roads assumes greater significance in such situations. The financial resources at the command of a maintenance engineer are always inadequate, necessitating the utilization of the resources in the most judicious manner by applying the best engineering practices and managerial skills (Anani 2008).

The process of road planning and designing is complicated and contains numerous components, which are to be considered for an optimal solution. Highway planning includes studying the conditions relevant to roads or improving already constructed roads on the basis of transportation demands, climate, topography, geology and material supplies. It includes evaluating the road and its consequences on society, transportability, traffic safety and economic development. The designing of the road implies selecting the dimensions and its components, such as width of carriageway, crust thickness and road profile, with respect to the type of road classified (IRC-SP-82, 1982).

Furthermore, proper maintenance is an important future aspect of highway roads. Often maintenance is required at a specific location on roads but their social and economic cost is very high because of VOC and travel time (IRC-SP-83, 2008). Such maintenance activities can be considerably reduced by suitable designs of highway roads (Coray 2009). Therefore, highway designers must take maintenance as priority.

1.5 HIGHWAY SAFETY

Highway safety is also included in this study's objectives. The safety of roads incorporates the development and management of road infrastructure, provision of safer vehicles, legislation in law enforcement and proper planning of urban land use (NHAI 2010). The success of road safety depends on the support and common action from all stakeholders including government, civil society organisations and road users. More than 60 years after India's independence, the transport system in the country has expanded and improved; moreover, continuous efforts are being made to make it safe and convenient. Management of the transport or traffic system is becoming difficult with increasing population and vehicles and the simultaneous growth of highways and other roads (NHAI 2012). The highway transport is managed by government agencies, namely the transport department and NHAI. These agencies are engaged in a constant struggle to make the system safe and overcome congestion with minimum maintenance of roads. However, according to the global safety report, the state of Indian road safety is quite alarming as they are associated with more deaths than Chinese roads. (WHO 2010).Therefore, the concept of road quality management and sustainability have gained momentum recently, leading policymakers and project managers to emphasise safety aspects in the transport system. The roads need proper design and regular evaluation at planning, construction, operation and maintenance stages to achieve accident free roads for an overall better safety performance.

Road accidents are undesirable events occurring on roads that involve vehicles causing damage to human lives and property. They are global phenomena; however, the situation is more serious because of poor traffic conditions that prevail on Indian highways. Worldwide, the number of people killed on road each year is estimated at almost 1.2 million, whereas the number of injured could be as high as 50 million, the combined population of five of the world's largest cities and account for 2.1% of global mortality. Developing countries account for approximately 85% of the total deaths (WHO 2010). It has been estimated that at least 6 million more will die and 60 million will be injured during the next 10 years in developing countries unless urgent action is taken. This indicates that if the rate of traffic death remains the same, the proportion for developing countries will rise as much as 80% by 2020. The road fatality rates in India are probably among the highest worldwide; every year, almost 10 out of 1,00,000 people are killed dues to road accidents (MORTH 2010; NHAI 2010; WHO 2010).

Table 1.4 presents the total number of accidents and accident-related deaths and injuries on the Indian NHs.

Table 1.4. Number of Accidents, Deaths and Injuries on NHs in India

Year	Accident		Death		Injured	
	Total Persons	**NH (%)**	**Total Persons**	**NH (%)**	**Total Persons**	**NH (%)**
2005	4,39,255	29.6	94,968	37.3	4,65,282	31.3
2006	4,60,920	30.4	1,05,749	37.7	4,96,481	30.8
2007	4,79,216	29.0	1,14,444	35.5	5,13,340	30.2
2008	4,84,704	28.5	1,19,860	35.6	5,23,193	28.6
2009	4,86,384	29.3	1,25,660	36.0	5,15,458	29.6
2010	4,99,628	30.0	1,34,513	36.1	5,27,512	31.3
2011	4,97,686	30.1	1,42,485	37.1	5,11,394	30.5
2012	4,90,383	29.1	1,38,258	35.3	5,09,667	30.1

Heavy traffic on highways invites more road accidents. This hypothesis indicates that poor maintenance and safety are somehow related to road accidents and accident-related deaths and injuries. Table 1.4 reveals that approximately 30% of the total accidents, deaths and injuries occur on NHs. However, the NH length is only 2% of the total road length in India. Furthermore, high speed results in relatively higher number of road accidents and fatalities (MORTH 2012). Moreover, arboriculture plays an important role in the road safety for which the following points below describe how landscaping and plantation of trees along the highway play an important role in providing road safety (IRC SP-21 2009):

- Definition of the toe and median of a carriageway, particularly of a horizontal sharp curve during night.
- Prevention of glaring from headlights of incoming vehicles.
- Control of erosion by turfing the slope of the embankments.
- Planting trees along the embankment slopes and near major water bodies controls erosion. Similarly, green cover in the form of turfing stabilises steep slopes and high embankment.
- Moderating the effect of wind and incoming radiation.
- Large trees with thick foliage provide much needed shade on glaring hot roads during summer.
- To define historical places by landscaping and turfing as per the existing scenario.

The hypothesis of efficient drainage systems on NHs and other roads for optimum maintenance and safety eliminates deficiencies, which in turn improves VOC and travel time. Adequate drainage is a primary requirement for maintaining the structural soundness and functional efficiency of a road. Pavement structure including subgrade must be protected from any ingress of water (Miller 2005). The drainage removes water from the pavement surface and reduces chances of skidding of vehicles. Because of inadequate surface drainage, the structural stability of pavement is undermined by:

- Weakening of the pavement structure and subgrade through infiltration of water from the top and
- Erosion of shoulders, verges and embankment slopes by water running off the pavement.

The importance of adequate and efficient drainage to the structural integrity of a road is well recognised. A drainage problem is caused by excess of water either on or below the surface of the pavement. Thus, the road drainage is categorised into

- surface water runoff and
- subsoil drainage

Reduction in pavement performance due to poor drainage is important hypothesis (IRC-SP-42 and 50, 1999).

1.6 RESEARCH GAPS

Several studies have been conducted on various components of highways in other countries but very few are on for Indian highways. In particularly, studies on maintenance and drainage system on highways are lacking. In India, specifically in Rajasthan, much importance has not been given because of deep water table conditions and filtration through large soil depth. In the present pavement design for Indian conditions, parameters of pavement deterioration, VOC and safety are must be considered when planning and designing highway projects. Other conditions including suitable traffic variation and weather and light conditions also must be considered in the planning of such projects. Utility aspects such as highway drainage, future maintenance and safety must be considered before planning and designing of a transportation project (WHO 2010).

Poor maintenance ultimately increases VOC and travel time. Therefore, provision for collection of suitable traffic study data regarding the aspect of maintenance and other activities is essential. In addition, some studies relating to climatic conditions, day–night, temperature and accidents have been conducted in developed countries but none in India. Various studies conducted on highway drainage conditions it was showed that during planning and construction of highway projects, due consideration was lacking for highway drainage, maintenance, safety and other utilities. The concept is usually considered in the execution of pavement surface water flow on the road-side borrow area or cross drainage. This is considered for surface water utilisation for arboriculture, aesthetics and other road side utilities (WHO 2013).

During site inspection, a highway official observes that most of the highways and busy roads get damaged during the rainy seasons because of high traffic intensity and longer duration of water retention time on pavement surface. The study of the concept of water retention on a pavement surface for highway roads is necessary to save maintenance costs. A highway drainage system should be modified such that it collects the entire water on the pavement surface within the least possible time. Sometimes, the water retention time is increased by local depressions or reverse slopes formed because of overloading and crust failure (WHO 2012). The camber correction and sealing of the pavement surface before monsoon also reduce the development of potholes, patches, ruts and other cracks, increasing safety and improving VOC, thus requiring minimum maintenance. Currently, catch water drains are being provided on highways to discharge increasing pavement surface water in side borrow pits and cross drains; however, because of increase in traffic, most highways and busy roads have been widened upto 4- or 6lanes with extra service lane surface area. Ribbon development slows the drainage of pavement surface water. The ongoing projects provide only catch water drains. The widening of highways upto 4-or-6-lanes lanes ultimately results in failure of such drains because of non availability of quick disposal of pavement surface water. Hence, more factors and their correlation with highway drainage, maintenance and safe traffic management on highways must be examined. Adverse conditions are created because of ribbon development and the increasing highway traffic. The collected pavement runoff water can be utilised for tree plantation and underground recharge. This will reduce or eliminate the problem of disposal of road side drains into cross drainage, which are mostly chocked or encroached. Hence, the current highway project is missing the provision of storage of rain water for tree plantation in footpath or medians and for recharging groundwater. In the present conditions, we must reduce the maintenance cost by minimising road damage and conserve water by improving greenery at road side (IRC-SP-21, 2009).

1.7 NEED OF THE STUDY

Indian highways carry more traffic density than highways of other countries. The increasing unplanned ribbon development along most of these highways seriously affects highway drainage and safety. Therefore, to change the situation of highway drainage for obtaining optimum maintenance and safety, a survey must be conducted focussing on the perception of highway managers and officials. The validation of these perceptions with secondary data is necessary for research. As in many fields, a gap seems to be present between the practitioner in the field and the research on system design. Researchers dealing with issues in these areas are largely ‘tinkering at the margin’ or using high-tech applications to develop recommendations for making the system safer and operationally more efficient (NHAI 2010).

Although the transportation engineers perceive the need of more safety in the system, a gap remains between what is really ‘known’ and what is ‘done’ in the field. Safety audits that find problems are that there remains great variation among agencies in a given state regarding when and how horizontal curves are signed and the appropriate advisory speed is determined. Hence, providing safer and more consistent designs remains a challenge and requires further research (MORTH 2012; NHAI 2012).

1.8 SPECIFIC OBJECTIVES

The following are the specific objectives of this research required for investigating highway drainage for optimum maintenance and safety.

1. Literature review to identify the role of important variable features on highway drainage, maintenance and safety.
2. Questionnaire designing for surveying the perception of highways with respect to select parameters.
3. To establish the correlation between selected good and bad features of the present highway drainage system and maintenance conditions including safety measures.
4. Highway drainage, poor maintenance and safety problems are indirectly related to road accidents.
5. To identify significant factors affecting highway drainage for future maintenance and safety.
6. To establish the correlation coefficient among highway accidents, rainfall data, maintenance and traffic flow on highways.
7. To examine features responsible for improving in highway safety and its proper maintenance.
8. To identify improvement in the existing drainage system on highways for better maintenance and safety.
9. The study of safety factor on the basis of accident data analysis.

1.9 ORGANISATION OF THE THESIS

This thesis comprises the following five chapters:

Chapter 1 of thesis includes the background of the road transportation system of India with classification and international comparison. In addition, it includes a brief study of the research topic contents such as drainage, maintenance and safety and introduces the objectives including research gaps.

Chapter 2 provides the literature review and theoretical consideration for drainage, pavement maintenance and safety; essential theoretical considerations regarding surface and subsurface drainage; and influences on pavements with subsoil drainage, including pavement drainage criteria combating moisture. Furthermore, the chapter briefly describes highway maintenance, transportation planning and operation, drainage system, pavement design, transport design and safety with state of practice.

Chapter 3 is based on materials and methods of the research methodology including data collection through a survey and various government websites. Moreover, statistical analysis is conducted to prove the hypothesis by using the Statistical Package for the Social Sciences (SPSS) method, Kendall rank correlation coefficient and factor analysis. Secondary data analysis, Analysis of Variance (ANOVA) model and analysis by using the multiple regression method are used to identify the regression coefficient including validation of results.

Chapter 4 presents the results and discussions of highway drainage, maintenance condition and safety by considering good and bad features of a highway design system including future suggestions required for alternate design.

Accident data analysis with other secondary data regression results is discussed to prove the hypothesis of the research objectives. The accident data analysis is performed to analyse the factor of safety on Indian highways.

Chapter 5 concludes the research with the future scope followed by references and an annexure of the questionnaire with photographs of the study area.

CHAPTER 2
LITERATURE REVIEW AND THEORETICAL CONSIDERATIONS

2.0 LITERATURE REVIEW

The importance of reviewing various aspects of qualitative and quantitative research for understanding a problem cannot be ignored. Literature review is crucial for finding the available deficiencies and further improving the state of knowledge in the chosen study area, that is, research on highway road drainage, maintenance and safety. Some previous studies briefly mentioned here provide a basic idea on the important research already conducted on the subject. The literature review has been conducted using representative case studies and articles to identify research gaps, and is classified by covering different aspects such as highway drainage, highway maintenance, socioeconomic impact, and traffic safety. Highway drainage studies conducted by Cedergren 1973, 1974, 1988; Gerke 1979; Lytton et. al. 1993; Tangpighakkul 1997; Shober 1997; Allen R. Long et. al. 2001; Ioannides et al. 2001; Yuan et. al. 2003; and Siew Ann 2003 were studied and reviewed to the understand drainage problem and thus identify gaps. Furthermore, recent studies conducted by Marina 2004, Nilesh Arjun Shirke 2009 were reviewed to understand the research objectives. Brief descriptions on the contents of the aforementioned studies on drainage are as follows.

2.1 STUDIES ON DRAINAGE

Various studies have been conducted on highway drainage, and few of them are briefly described in the following text.

Road pavements are mostly distorted because of excess moisture in the foundation resulting from water logging, high traffic volume, and heavy vehicle loads. Road designers know that water flowing inside or next to a road structure for long will shorten its life. Following are a few studies related to highway drainage.

Barber and Sawyer (1952) concluded that free water in pavement layers decreases the strength in the base, sub-base, and subgrade and is a major concern. The presence of free water decreases the strength of a road in several ways. This reduces the apparent cohesion and decreases friction by reducing effective stress of the materials below the water table.

The pavement service ability performance concept was introduced to view the performance characteristics of flexible pavements, the relationship between the stress–strain response of asphalt concrete under cyclic loading, threshold values for the friction index, and crack propagation between beam specimens and layered pavements, which are important parameters. In the past, studies on the fracture behaviour of the interface between the interlayer and asphalt overlay as well as the entire overlay of the pavement system have also gained popularity.

In addition, an increasing interest is observed in the area of pavement system management over the past two decades. A good understanding of the flow of water in the subsurface of the pavement may enable. The design of pavement drainage systems identified that to prevent excess moisture in the pavement system, the pavement sub-drainage system should be designed using materials that have enough permeability.

The time required to drain water at the end of the inflow period must be short for the excess water not to remain in the structure long enough to freeze (in cold places). The use of free draining materials in base and sub-base construction has improved pavement performance. The effects of excess moisture and the duration of time water is retained within the pavement system guide pavement design. In addition, this refers to specific structural requirements for pavements, which are weakened due to the effects of moisture (Cedergren 1988). The magnitude of structural factors is directly related to the time the moisture is retained in the structure. Not only the design of new pavements but also the evaluation of existing pavements depend on the moisture retained. To sustain heavy loads, the water should be able to flow out of the pavement faster than it enters.

The rapidly applied loads cause increasing oscillating pore pressure. Cedergren et al. (1973) reported that water in the form of rains or other sources in pavement layers produces a moving pressure wave, thus creating a large hydrostatic force. Movement of wheels on a pavement with a saturated subgrade produces a moving pressure wave, which in turn creates a large hydrostatic force within the structural section. These pulsating pores influence the load-carrying capacity of all parts of the pavement structure (Cedergren 1974).

Gerke (1979) states that premature failure of a road structure is defined by poor construction, incorrect material usage (including incorrect design assumptions), and moisture conditions. The structural and functional failure causes excessive water presence in the pavement base and sub-base, including subgrade soils. The water-related damages are as follows Reduction of subgrade and base or sub-base strength, differential swelling in expansive subgrade soils, stripping of asphalt in flexible pavements, frost heave and reduction of strength during frost melt, and movement of fine particles into base or sub-base course materials, considerably decreasing in hydraulic conductivity.

Lytton et al. (1993) studied an integrated model of climatic effect on pavement rapid decrease in the level of serviceability, which considerably weakens the pavement ability to transmit dynamic loads imposed by the traffic.

Reports on many systems require intense maintenance programmes for the systems to perform moderately. Grassy swales performed more satisfactorily than other runoff control options with low cost and low maintenance costs.

Shober (1997) warnedabout the dangers of partially sealed joints for removing and replacing all sealants having an average effectiveness below 75%: these are ineffective at preventing water and are incompressible. David (1997) determined the drain ability characteristics of several types of unbound granular materials used in a pavement base. Hydraulic conductivity and effective porosity are determined to aggregate two sources of crushed stone and two sources of gravel. For each material, two open gradations were tested in a rigid wall permeameter. Furthermore, one dense gradation of each material, at thetwo levels of compaction was tested in a flexible wall permeameter. Efforts were made for reducing the flow along the sides of the rigid wall permeameter and eliminating problems with air bubbles.

Robert (1999) explained that water infiltration and seepage in a roadway infrastructure is modelled using a cross-section design of a residential street used by the City of Moncton (Department of Engineering). Osman Akan (2000) determined the spread calculations in a composite spread in routine pavement drainage problems. The use of the chart was demonstrated through a practical application.

Allen et al. (2001) investigated the subsurface drainage features of a test pavement and found that the specified base thickness and permeability combination does not meet federal guidelines; evidently, no design calculations were performed prior to construction. A field inspection of the test pavement drainage features revealed that these receive very scant attention for maintenance.

The monitoring should extend over both sealed and unsealed test sections of a joint to confirm the established routine survey, which consists of the continued monitoring of the joint sealant (Ioannides et al. 2001). The field results validating with laboratory are conducted on a number of roads indicating that the moduli of base and subgrade materials are strongly affected by the moisture content. Siew-Ann (2003) demonstrated the clogging of void spaces within the permeable base because of foreign particles, which can severely reduce the drainage capacity of the base. In addition, it reduces the service lift of the permeable base layer within the pavement. The vertical permeability of several permeable base mixes reduces because of clogging. The clogging materials include a mixture of sand and residual soil. An empirical theoretical formulation has been derived from the Kozeny–Carmen equation for predicting the reduction in the permeability of permeable bases.

Marina (2004) showed that the highway runoff haspollutants in concentrations, that harm freshwater ecosystems. Thepreferential flow pattern resembles macro-porous flow through physical voids in heterogeneous construction materials (stony loam) and at borders between construction materials with different textures (gravel, clayey till, fine and coarse sand). At two sites, which were built almost exclusively from homogeneous sand, the flow patterns resembled fingered flow initiated around thin, deep-running roots from the surface vegetation.

The tracing at the four Danish highways was suggested to allow highway runoff to infiltrate the top layer of roadside swales uniformly in a plug flow mode and the lower layer less uniformly in a preferential flow mode. The plug flow occurs in a homogeneous 2-to 10-cm cm thick layer of a dark-coloured sandy material that overlies the original swale surface at all the sites, and accumulates at an approximate rate of 1–6 mm per year. The preferential flow patterns reflect the heterogeneity of the material used in swale construction. In heterogeneously constructed swales, the flow paths have a permanent character form in the physical voids and at the textural borders of materials with different capillary forces. In homogeneously constructed swales, flow paths are formed along deeply penetrating roots. The dissemination of a highway, which derives contaminants with runoff infiltrating highway swales, is limited by the grass-lined swale surface, which effectively filters out at least part of the suspended solid loads and possibly of other contaminant fractions. Deep transfer of contaminants through the swale profile is favoured by the presence of preferential flow paths, as was observed in 3 of 4 investigated sites, particularly if the pathways are of a permanent character, which seems to be the case at two sites.

Al-Qadi (2004) determined 2-fold objectives for quantifying the benefits of a specially designed geo composite membrane [a low modulus polyvinyl chloride (PVC) layer sandwiched between two nonwoven geotextiles to act as a moisture barrier in flexible pavement systems and quantitatively measure the moisture content of unbound granular materials nondestructively. The study was conducted on Virginia Smart Road, the half section installing geocomposite is with other half road length in same design without the interlayer system. Ground penetrating radar (GPR) having air coupling of 1 GHz detected the moisture content within the pavement system. The geo composite membrane represented less deflection in the area without an interlayer. Hence, the pavement drainage layer must be backed by an intermediate interface.

Bjensen and Holm (2006) studied the effect of a black is haccumulation on highway sides in France, Switzerland, and Germany. Similar contents of metal-like oxides, carbonates, organic matter, and clays at the investigated highways suggest that the deposited material possessed high capacities for the retention of inorganic and organic contaminants.

Nilesh (2009) highlighted moisture flow from the surface into underlying reservoirs or subgrade soils for the designing of porous pavements. The clogging of voids in porous pavements is a critical problem. Moreover, the back flushing system must remove the clogging of voids.

2.2 HIGHWAY MAINTENANCE

In other countries, many studies have been conducted on highway maintenance; however, they are limited in India. Various studies related tomaintenance have been, reviewed and a few are briefly described here to understand the hypotheses and objectives of this research. The recent studies during 21st Century by Jose (2002); Anani (2008); Hawzhen (2008); Anani (2010); Reddy (2010); and Nagbushana (2010) on highway maintenance are briefly reviewed to identify the research gaps for the objectives.

Jose (2002) attempted to estimate road transport costs on the basis of cost derived from maintenance investment policies. The study was conducted in Spain on existing models to estimate the best investment strategy for fixed budgetary resources. However, it does not consider the effects derived from work productivity increments arising from new contracting formulas. The study describes a simulation model for estimating the overall benefit derived from the use of different systems for financing road maintenance and the productivity achieved in managing the work. To validate the model, the paper concluded with an application on a secondary road in Spain. The results of the simulation showed that work productivity is extremely important for optimal level of investment. Moreover, the simulation provides some relevant conclusions regarding finance-tested mechanisms.

Anani (2008) perpetually assumed that pavement deterioration caused by a fourth power of the axle load with reference to the performance indicator used during highway maintenance. In addition, pavement deterioration is determined on the basis of the exact number of all future monthly repair (MR) and repair (R) activities that can be exactly predicted.

Hawzhen (2008) determined the hindrance that prevents future road maintenance required during the initial planning stage. The study was conducted by the Swedish road administration. The Nordic conditions, road design, maintenance, and climatewere considered for applying the results. The investigation was conducted using a method called 'change analysis', which consists of complementary steps. The result obtained was the insufficient consideration of maintainability during the planning design process.

Hawzhen’s study increased the efficiency of maintenance activities dealing with future challenges regarding funding gaps; implementation of these changes require additional studies for establishing effective and long term solutions.

Anani (2010) focussed his study on the estimation of the marginal cost for highway maintenance. The marginal cost of highway maintenancehas been estimated in the literature by using anindirect approach of perpetual overlay. The approach assumes that pavement overlay costs dominate maintenance costs and ignores other maintenance activities. The realistic volume of MR and R marginal costs should be considered forweathering effects.

Reddy’s (2010) study analytically obtained the dynamic amplification of vehicle response that is passing over a series of potholes. A generic vehicle model with single degree freedom system was considered to travel at a constant velocity over a series of potholes. The suspension stiffness and damping have been assumed to be linearand the closed form expression for the response was derived using Duhamel's integral. A parametric study was conducted to examine the influence of pothole parameters, such as width and depth, vehicle velocity, suspension stiffness, and damping on the dynamic amplification factor of the vehicle response. The result showed that when a vehicle crosses over a series of potholes of similar character at regular intervals, the response tends to be in a steady state after the initial few potholes. For a certain pothole width, the critical velocity determines the maximum response in the vehicle. For determining ride comfort, the parameter 'jerk' was found to be most sensitive to the change in velocity. A technique for detecting time is a dependant trend in axle load distribution, which is proposed by the marking use of

Gaussian parameters. The parameters remain more or less the same over time. The marginal changes in Gaussian parameters are attributed to the local factors or time of the year during which the data were collected. Additional studies are required to exactly identify the factors influencing these parameters.

Nagabhushana (2010) presented that roads are infrastructural assets and require proper timely maintenance for their upkeep and for better and safer intended services. However, the maintenance and rehabilitation of metropolitan city roads in India encounter various problems including the following:

- Geometric and drainage problems are caused by raising of the pavement height because of repeated resurfacing by conventional hot mix technologies.
- High expectations of road users with respect to clean environment, comfort, safety, and mobility with least disturbance to traffic during maintenance and rehabilitation activities.
- Difficulties due to closure of hot mix plants in the vicinity (Delhi) to mitigate environmental pollution. The lack of a road condition database also poses several problems in decision making regarding study of suitable and economical maintenance and rehabilitation treatments. Various options are considered for pavement maintenance and rehabilitation strategies. Cold mix technologies such as micro surfacing, have been given preference as a preventive measure, whereas surfacing with modified binder and stone matrix asphalt are considered for the maintenance of roads with heavy traffic and under designed pavements. The maintenance and rehabilitation of urban roads have more specific problems and dimensions. The approach for evaluating the needs and the considerations for best options is rational and

logical. The life expectancy of road pavements is higher because frequent interventions are not desirable. The case study on the Delhi road network established the fact that the conditions are typical and complex; hence, strategies must be smart enough to provide satisfactory solutions.

2.3 SOCIOECONOMIC IMPACT AND TRAFFIC SAFETY

In India, very few studies have been conducted on the socio economic impact and traffic safety unlike in foreign countries. The few studies conducted on the socio-economic impact of traffic safety are being reviewed briefly to understand the objectives of the research hypothesis:

We identified that the indicators, proper drainage design and highway maintenance, apart from users and vehicle conditions, are necessary for highway road safety. Other factors, such as landscaping and plantation along the highway, toe and median of the carriageway, especially horizontal sharp curve, glaring headlight of incoming vehicles; and control of erosion on the slope of the embankments are also equally important for highway road safety. Furthermore, recent studies, such as those of Thomas (2003), Christopher et al. (2008), Davis (2009), Tamer (2011), and Jansch et al. (2009), were reviewed to identify research gap for safety.

Thomas (2003) applied linear and nonlinear multivariate statistical analyses to determine how types of accidents occurring on heavy user freeways in Southern California are related to the flow of traffic, weather, and ambient lighting conditions. Traffic flow is measured in terms of a series of 30-s observations from inductive loop detectors in the vicinity of the accident prior to the time of its occurrence. The results indicated that the type of collision is strongly related to median traffic speed and temporal variations in speed in the left and interior lanes. Hit-object collisions and collisions involving multiple vehicles associated with lane change man oeuvres are more likely to occur on wet roads, whereas rear-end collisions are more likely to occur on dry roads during daylight. According to weather and lighting conditions, accident severity has been evidenced to be influenced more by volume than by speed.

The enhancement procedures and recalibration with more recent accident and traffic flow data are necessary before any large-scale deployment of the toll, and is an important subject for future research.

Tamer (2011) reported the importance of accurate climatic data investigated using a case study. The study showed that the implementation of the new mechanistic-empirical design guide led to the requirement for more accurate inputs. Climatic data are one of the most important inputs that affect the performance of pavement materials. Its importance is investigated in the case study. Climatic files available with the design guide and developed on the basis of historical information for countries in the state of Lowa through the Lowa Environment Mesonet were used. The climatic files that were interpolated from the data available within the design guide predicted higher rutting (both total and asphalt cement layer) for the northern part of the state; the lower thermal cracking and the lower international roughness indices were compared to the files developed in the study. Statistical analysis showed that the results calculated using both groups vary.

The case study illustrates the critical role that accurate climatic data plays in the M-EPDG, and thus, using the forecasting climatic data in developing pavement design for future designs is likely to be very important in developing appropriate designs.

Christopher (2008) attempted to identify crass location by using significant data requirement, which highlights that the techniques for screening transportation network to identify high crash locations have recently become more sophisticated. The study presents the results of an empirical analysis of screening and ranking for weather-related crashes on rural [1.6 km (1 mi)] highway sections of Oregon highways. The analysis includes data generation by extensively using spatial techniques and incorporating climate data to enhance environmental considerations. The study compares the results of five ranking methods, that is, ranking the critical rate by functional class, climate zone, potential for crash reduction, expected frequency (adjusted by empirical–bayes),and frequency. For the empirical–bayes methods, safety performance functions are generated using negative binomial regression techniques. The 20 top 1.6-km (1-mi) sections are identified for each method and compared. The results revealed that the frequency and expected frequency methods identify most common sites, followed by the rate-based methods. The potential for the crash reduction method identifies the most unique ranked list. Although this research effort focused on identifying segments related to speed and ice conditions, the methodology could be applied to any number or combinations of crash variables. Finally, the treatment of severity or crash type in network screening should be explored.

The study by Davis (2009) is based onthe population of fuels of highway vehicles. It determines the socioeconomic effect of highway improvement on low-income families. The general methodology can be applied to various income classes to determine the extent of the impact caused by new highway construction. Penalty costs are chosen and used to penalise highway alignments crossing low-income areas. Multiple values for penalty costs are used to test the sensitivity of the generated alignment. Tests are performed to examine the robustness of the developed methodology. The results lead to the need for establishing appropriate penalty costs, which is suitable for avoiding low-income areas. This research is the first step in quantifying the impact of highway construction and expansion on low-income families.

The census data allowed for producing alignments are sensitive to the socioeconomic characteristic. A GIS is a great resource for automating the neighborhood cost calculation. This enhances the practical applicability of the previously developed highway alignment optimization model by using data that represent socioeconomic change with the highways data simultaneously in a topographical environment.

Otte et al. (2009) highlighted the more important accident causation data research. The German in-depth accident study (GIDAS) is well qualified to deliver adequate data to conduct an investigation in this field by identifying the causes of accidents. This study led to the development and implementation of a special tool called the accident causation analysis system (ACAS) for collecting such causation data by adopting the GIDAS methodology.

With this system, for each accident participant, one or more of five hypotheses of human cause factors were identified along the basic human functions when managing a situation in traffic. The hypotheses are subsequently specified using an appropriate verification criteria. To facilitate the analysis of accident causes, information collected with ACAS is recorded in a structured code of digits. Structured questionnaires for on-scene investigation by the accident participants makes it possible to easily identify human failures and categorise these in the ACAS structure. Internal analysis of accident causation information has proven that causes of traffic accidents may be found using this system with enough details to identify differences in psychological performances categorised by the basic human functions in the situation or the emergence of the accident.

Past studies for identifying typical accident scenarios of elderly traffic participants have shown that finding typical circumstances and features of accidents caused by classic accident research data are difficult. This study focusses on identifying the special causes of elderly traffic participants and analysing the psychological effects, which lead to failures resulting in the accident. The results of the causation analysis display that with elderly traffic participants, the human failures are mostly due to perception problems and difficulties while executing a desired action. The study also reveals that the causation category of an accident has an influence on the accident severity (injury outcome). This is an important factor, which must be considered when looking for counter measures to decrease severe injuries or fatalities.

The analysis and evaluation of accident causation data are necessary to prevent the occurrence of more accidents. In addition, knowledge regarding human failures is essential for various processes, such as the development of driver assistance systems. ACAS is a European methodology for collecting accident causation data. It is used in Germany in the frame work of the GIDAS accident data collection. This study illustrates ACAS in the context of reflecting the differences in the causation factors by comparing younger and older car drivers involved in accidents. The study was conducted by focusing on and analysing the human factors (human failures) along with the ACAS-classification scheme of five categories of basic human functions that are effective when coping with driving.

For assessing human accident causes using ACAS, approximately 817 non-elder car drivers (age 25–64 yrs) and 169 elder car (age 65+ yrs) car drivers were selected from the GIDAS database, which contributed to the emergence of an injury accident. The causation factors collected for these two age groups were analysed according to the main human failure categories and for additional details concerning the subcategories criterion of the main categories. The nonelderly car drivers demonstrated more failures from the following categories: information evaluation (misjudgement of a situation) and the planning of an appropriate action (e.g., intentional breach of rules). In comparison, the elderly car drivers frequently faced problems with the admission of the necessary information (perception) in a traffic situation and the operation of the vehicle. The relevant information often was not perceived by elderly car drivers because of age-related disease symptoms and they frequently faced difficulties while executing of an operation due to restricted mobility.

2.4 RESEARCH STUDY CONSIDERATIONS

While reviewing literature, a thorough knowledge of few theoretical considerations, which are the key points of this thesis, is required before field study and data collection. The highway drainage considerations highlight the drainage system, type of drainage as per flow, cross drainage, the factors influencing drainage system, sub–surface drain importance, pavement surface defects, surface water runoff harm, sub–soil drainage, and subgrade water content. Pavement drainage criteria moisture with the design consideration is an essential feature of research study. In addition, understanding the drainage system with pavement design is essential. The analysis of the drainage system using rainfall data is necessary to hypothesise objectives. Furthermore, highway road maintenance and transport design with road safety in India is a key feature that must be explained before research.

2.4.1 Highway Drainage Systems

A drainage system is constructed along with highways for removing rain water and moisture from its surface. The two types of drainage systems constructed along the highways are as follows: The surface drainage system along the highways includes water proofing the top surface with a camber leading to surface drains and the subsurface drainage infiltration through pavement surface and ground water. In the event of poor drainage, water enters in the pavement layers reducing the bearing capacity of the road, and thereby its lifetime. In cold climates, this problem is magnified by the risk of frost damage when water is present (Hagen et al. 1996). Therefore, well-performing drainage systems are necessary in a road design. Roads are constructed with two types of drainage systems, each taking care of their source of moisture:

- The surface drainage system removes runoff water (rainfall). A new pavement has a waterproof surface with a cross fall that leads the rainwater to the surface drains.
- The subsurface drainage system, which removes groundwater and water infiltrating through the pavement surface.

2.4.2 Surface Drainage

The removal and diversion of surface water from the highway and adjoining land is termed as surface drainage. The surface water is collected and disposed to a suitable place. The water is first collected in longitudinal drains, generally the side drains, and is later disposed into the nearest stream, valley, or water course. Structures, such as culverts and small bridges, may be necessary to dispose surface water from the roadside drains. Surface drainage deals with the arrangements quickly and effectively removing water that collects on the surface of pavements, shoulders, slopes of embankments and cuts, and the land joining the highway. The collected water is led to natural water-channels or artificial channels, without interfering with the proper functioning of any part of the highway, including the embankment, pavement shoulders, medians, slopes, and structures. Because of the increased traffic along the highway roads and nearby areas, the situation of the aforementioned surface drainage system has changed, and therefore requires further research (Wyatt et al. 1998).

The surface drainage must be made on a piped system to save space and discharge the runoff water. Studies have estimated that approximately between 80–100% rainfall arrive in the surface drainage system because of the use of piped system. However, most of the runoff water might not necessarily enter the pipe system because water may run into ditches also soaks into the ground (Miller 2005). The remaining water penetrates into the surface drainage. In older pavements with increased cracking, the percentage of water that runs through the cracks might be as high as 20–50%. Therefore, a regular and proper maintenance of the pavement surface is crucial. A ribbon development along highway and the widening of roads up to 4 and 6 lanes causes serious problems of surface water runoff and the presence of heavy traffic damages the pavement surface in rainy season. Therefore, suitable changes in the highway drainage system is of utmost importance (Johnson et al. 1984; storm water centre.net 2005).

2.4.3 Sub-Surface Drainage

The diversion or removal of excess soil water from the subgrade is termed as subsurface drainage; it varies alternatively in complexity and cost, ranging from the provision of open-graded drainage layers. A permeable base system is the most competent subsurface drainage alternative because it incorporates most of the drainage-related components. Because designing a drainage layer that will never perish is almost impossible, the drainage layer was designed to satisfy three typical conditions:

- To provide adequate permeability for transmitting all infiltrated water during rain under partially or fully saturated flow conditions.
- To limit the time in which the drainage layer is fully saturated to a relatively short duration (few hours or less after the rain stops).
- To provide sufficient structural stability to support pavement construction and traffic load (Ridgeway 1982).

The water that enters a pavement has a detrimental effect; therefore, a proper drainage increases the life of a pavement. Contrarily, some experimental results regarding the benefits of subsurface drainage are uncertain. Subsurface drainage adds to the complexity and cost of pavement construction. The decision-making methodology or criteria regarding subsurface drainage varies with an agency. Christopher and McGuffey presented results regarding the inclusion of subsurface drainage elements from a survey of agencies throughout the United States. The results indicated that subsurface drainage is employed by many agencies throughout the United States, although the criteria for the drainage decision are apparently inconsistent among the agencies. For example, some agencies, such as California always include drainage beneath concrete pavements (Wyatt et al. 1998). Other agencies focus on the anticipated traffic load: A heavier traffic load indicates a greater need for sub-surface drainage. Hence, in the case of increased traffic, the importance of subsurface drainage must be considered.

Subsurface drainage ensures that the water that finds its way into the pavement crust form the surface or ground, which must lead out of the pavement curst again. The system can be simply made up of porous materials (drainage layers) or drainage pipes or both. Variations in the moisture content of subgrade are caused by fluctuations in the ground water table, seepage flow, percolation of rain water, and movement of capillary water and water vapour. In the subsurface drainage of highways, the variation of moisture is attempted to be maintained in the subgrade soil. An optimum performance of a pavement system is achieved by preventing the entry of water using a well-designed sub-surface drainage system. Most highways and airfield pavements built in India in the past 30 years have extremely slow drainage system largely because the standard design practices emphasise on density and stability but place and overlook subsurface drainage. The damaging effects of excess moisture, which enters a pavement’s structure, have been identified. Furthermore, moisture in the subgrade and pavement structure can enter from different sources. Water may seep upward from a high ground water table or it may flow laterally through the pavement edges. Knowledge about ground water and its movement is critical for the pavement performance and the stability of the adjacent side slopes. Ground water can be particularly troublesome for pavements in low-lying areas (Yu et al. 1998). Pavement failure occurs when the pavement is below the general ground level or the water table is considerably high. The combined effects of moisture in the pavement and heavy traffic load reduce the overall performance of a pavement system (IRC-SP-42, 1994–2004).

The water penetrates pavements through joints, cracks, and other defects in the surface that provide an easy path for subsurface water. This problem increases with the age of pavements because of deterioration during which some cracks become wider and more abundant. The joints and edges deteriorate into channels through which water flows freely (UNI-group 1998). This causes more water to seep into the pavement structure, which in turn leads to accelerated moisture distressing and pavement deterioration. Excess moisture in a pavement structure can adversely affect pavement performance. A pavement structure can be stable at prescribed moisture contents and may become unstable if the materials get saturated because of high water pressures develop under heavy traffic. Water in the pavement structure can freeze and expand, thus developing high internal pressures on the pavement structure. Flowing water carries soil particles leading to clogging of drains with increase in traffic.

Subsurface drains are chosen on the basis of various factors, such as the ground water distance between the pavement construction and ground water table. The required distance is suggested to be between 30 cm and 3.2 m, approximately; it can vary depending on the depth of the water table. Wherever the ground water is at a shallow depth, the drainage layer is often thicker, an extra drainage layer is constructed, or drain types that transport more water are chosen. The most commonly used edge drains for collecting subsurface water are in the form of a pipe at the bottom of the drain edge. The pipe leads the water to the drains; the subsurface water is often combined with the surface water. During this study, Author observed that for most highways, the drainage water disposal problem was due to quick ribbon development, rapid transport development facility, and abrupt change in the use of land. Hence a systematic research felt essential by preparing well designed questionnaire.

2.4.4 Cross Drainage

Whenever a highway is constructed over a river or stream, cross drainage is provided. Sometimes water from the side drains is also diverted away from the road through cross drains. In general, highways involve a mechanism that makes the water cross up to 6 metres, and such cross drainage structures are called culverts. A structure with higher discharge and greater linearity is called a bridge (IRC-SP-42, 1994-2004).

2.4.5 The Factors Influencing a Drainage System

1. Drainage layer
2. Flow of water

A drainage layer is important in a drainage system. The subsurface drainage system includes a (permeable) drainage layer in the pavement. Some countries always use a drainage layer in standard designs, and finding any country not using a drainage layer is rare. There are different national conventions based on which a layer in the pavement works as a drainage layer (Hawkins et al. 2001). A drainage layer, is essential for draining subsurface water and prevents pavement decay. The layer might more or less clog with time. The fine particle content might increase because of the degradation of aggregates and/or migration of fine particles from other layers, which causes decreased permeability and increased frost susceptibility (Bean et al. 2004).

Water flow in the pavement layers reduces the bearing capacity of roads and thereby their lifespan. In cold climates, this problem increases because of frost damage in the presence of water. Therefore, well-performing drainage systems are important in highway road designs.

The drainage of surface and subsurface water is vital in road designs and construction. From point of view of the landscape, surface water is a major concern. Water collection on the roadway or uncontrolled water collection on the adjoining highway land is not only harmful to the road structure but also not permissible from the landscape point of view. The disturbance to the natural drainage must be minimum (Lovering 1960). In many cases, it is be possible to develop low-lying areas by the roadside into beauty spots by using a suitable plantation scheme, or take advantage of the natural tendency of water to route towards a pond. For ensuring better surface water drainage, the road camber should be consistent with the rainfall of the area and the surface texture of the road surfacing.

In addition, shoulders should have the requisite slope, and the profile between the pavement and shoulder should be without breaks. Side drains should be appropriately connected to natural outfalls. Wherever necessary, intercepting drains should be provided and other measures must be taken to protect natural surfaces from water erosion (IRC-SP-42, 1994–2004). Surface drainage in urban areas is generally ensured through a gutter and curb arrangement with drain inlets connected to the storm water system. Desirably, all unpaved areas in highway cross-sections should be provided with erosion-proof turf to prevent soil from being carried into the storm sewer system. A lack of effective erosion control may result in small channels or eroded areas, which may be costly to repair (Bowyer 1991).

2.4.6 Importance of Subsurface Drains

Regular checks and maintenance are required for the drainage systems to work properly. The intervals of monitoring vary greatly from after construction or when pavements show distress to a specified interval in drain maintenance guidelines, (every two years). Inspection can be both visual and on video, depending on pipe diameters and drain types (Burk 1991). The problem encountered with sub-surface drains is that they fill with impermeable materials or clog particularly after heavy rainfall. Collapse of asphalt-treated drainage layers, normal deterioration, crushed pipes, poor outlet conditions, outlets with a negative slope, poor compaction of asphalt cap materials; difficulty in inspection of long mainline pipes (>50 m); root penetration; generation of ferrous oxide and calcium carbonate; insufficient capacity; inadequate water velocity; the (plastic) damage of the cover for inspection at the slope (sometimes because of the snow clearance of roads); and access for inspection and/or remediation is not possible. The subsurface drains, if used as a combined (French) drain are known to deteriorate the road foundation because of large volumes of water being introduced into its when the system is blocked up (Hassan et al. 1996).

2.4.7 Drainage with Pavement Surface Defects

The defects of the first part include fatty surfaces, smooth surfaces, streaking, and hungry surface. Cracks (hair line cracks, alligator cracks, longitudinal cracks, edge cracks, shrinkage cracks, and reflection cracks) are dealt with. The deformation of the second part are grouped as slippage, rutting, corrugations shoving, shallow depressions and settlements, upheavals and disintegration covering stripping loss of aggregates, revelling, potholes, and edge breaking (Peshkin et. al. 1989). The improvement and development projects on highways require the inclusion of a proper drainage for optimum maintenance and safety. This improves VOC and travel time by introducing an adequate drainage system considering future maintenance and site conditions of highway. Adequate drainage is a primary requirement for maintaining the structural soundness and functional efficiency of a road. Pavement structures, including subgrade, must be protected from any ingress of water, which will otherwise weaken the sub-grade by saturating and causing distress in the pavement structure (Bean et al. 2004). Therefore, new rapid dispersal of water from pavement and subgrade is a basic consideration in highway design systems. Quick drainage implies the removal of water from the pavement surface. This reduces chances of skidding of vehicles because of inadequate surface drainage. The structural stability of pavement is dependent on the strength of the pavement structure and subgrade, which might weaken by the infiltration of water from the top. The shoulders, verges, and embankment slopes are eroded by water running off the pavement (Hall 2003). A drainage problem is caused by excess of water either on or below the surface of the pavement (Bruzelius 2004).

2.4.8 Surface Water Runoff Harm

Water must be removed from areas of the carriageway or footpath, where its presence would be harmful or dangerous to road users, because it leads to deterioration. Flowing water has the capacity to damage roads when flowing down the shoulders and side slopes (Wada 1997). In this process, the water causes erosion and again deposits the material causing siltation at another point and both require provision of measures to reduce the damage because of (Georgia S.W.M. Manual 2002). In situations including incorrect road profile and in conducive and slow drainage, pools of water may form, thus weakening the pavement course and leading to skidding, hydroplaning, or splashing of water, which is a nuisance to vehicles and leads to accidents (Pratt 1995).

2.4.9 Subsoil Drainage

Subsoil drainage sustains the stability of pavement within design tolerances. In many instances, the soil surface may appear dry, although waterlogged soil below subgrade may cause serious damage to the road crust. The water may enter the sub-grade from the ground by infiltrating the surface of pavements, shoulders, and verges (Izzard 1944). The water must be collected by subsurface drainage systems, which in turn discharge it into a clear drainage system of the road (Mottola 1991). The investigation methods for estimating the rates of surface water infiltration, ground water levels, and form of flows are important for engineering a drainage system. The study of pavement drainage of both flexible and rigid pavements concluded that the drainage should be treated as a series of permeable layers and added that precautions are necessary to protect the subgrade (Robert 1999). The use of self-draining materials and introduction of membranes have facilitated in controlling the migration of fine materials from the subgrade (pumping).Relatively small migration of fine materials from the subgrade into the sub-base voids can critically reduce the capacity of the sub-base to act as a lateral drain.

Urban roads are usually on flat terrains. The urbanisation of areas and intense density of construction requires a well-planned drainage system. Roads and highways do not have distinctly separate drainage systems. Water from the road joins the road side drain through inlets or gratings. For effective drainage, this should join the peripheral drains, which in turn should join the main drain trunk for ultimate discharge to the natural drain (Wyatt et al. 1998). It would be necessary to divide urban areas into drainage basins. Therefore, storm water drainage must consider alignments, ground levels, and outfall levels. Existing drains pass through highly developed and thickly populated areas, which may cause a problem of land availability for increasing the capacity of drains. Besides, these drains should be able to cater to the increased discharges resulting from new colonies and urbanisation. An important aspect of such drains is to ensure a good velocity. In general, silt and other materials collect in large quantities in the bed to the design needs to ensure self cleaning velocity during dominant and also in lean flow conditions (Ridgeway 1982).

In most urban areas, the responsibility for the design and construction of peripheral and trunk drainage systems rests with local bodies, for example, the Municipal corporation. The report emphasises on the role of a proper drainage to ensure longevity of pavement. Among the measures mentioned herein to guard against poorly drained conditions is the maintenance of transverse sections in a good shape to a reasonable cross fall to facilitate quick run-off of surface water and provision of appropriate surface and sub-surface drains. Some other measures include extension of granular sub-base over the entire formation width, provision of drainage layer, and adequate height of formation level above HFL/ground level. In addition, infiltration of water under the pavement through adjoining earth shoulders (verges) is a major cause of weakening of the pavement. Road design must take these causes into account.

Poor drainage causes losses, which are direct and indirect in the form of damaged highways and reduced serviceability. Despite the recurring losses incurred by the society and government, drainage systems are not as adequately prioritised as infrastructure in India. Adequate priority should be given to drainage development and satisfactory arrangements must be ensured by proper designing and planning (Brown 2003). Despite measures for the quick drainage of the pavement surface and provision of a fairly watertight surface, water enters from the top and travels through various pavement layers and accumulates at the interface of subbase or base course and subgrade. The boxed-type pavement section causes considerable functional problems in new road constructions. The aspect can be dealt by providing a drainage layer at this level in the existing boxed-type pavement construction (Brown et al. 1996). Because of acute problems, special measures must be thought and taken as per actual site requirements for draining out the locked water (IRC-SP-42, 1994–2004).

A clear idea was obtained about the internal drainage of a pavement structure including permeability reversal conditions where an impervious course is overlaid by a more pervious course. A stabilised soil layer overlaid by water-bound macadam is essential for avoiding pavement structure malfunction because of inadequate drainage facilities; therefore, the pavement behaviour should be understood. Suitable remedial measures must be taken to ensure the desired performance during the service life of the pavement (Moulton 1980). Considering the importance of the drainage of highways, we decided on guidelines for features covering the specific requirement for different situations in addition, a questionnaire was also prepared.

2.4.10 Water Content Sub Grade

The parameter of the resilient modulus of soil is important. The resilient modulus of cohesive soils is not a constant stiff property and highly depends on factors, such as the state of stress, soil structures, and water content (Baldwin 1987). Because of the complexity of conducting resilient modulus testing, numerous efforts were made to develop the predictive equations by incorporating state variables, such as confining stress, bulk stress, deviator stress, and soil physical properties (Hajek et al. 1992). Because of its sensitivity, the resilient modulus of cohesive soils depends on the water content and stress state. The soil's moisture is likely to vary underneath the pavement. The development of a simple and accurate prediction equation for predicting the variation of the resilient modulus because of changes in the stress and moisture content of cohesive soils is important (Hall 2003).

2.4.11 Drainage Effect on Pavement Design

The principal cause of premature pavement failure is the presence of water in pavement systems. The Indian road network, with more than 3.3 million km is under one of the world's longest road networks (Ioannides et al. 2004). Most highways built in our country have very slow drainage systems, because standard design practices emphasise on density and stability and place little importance on the subsurface drainage. The poor subsurface drainage on highways leads to extensive costly repairs or replacements long before the roads reach their design life (Heckel 1997). Subsurface drainage is a key element in the design of pavement systems. Indiscriminate exclusion of this element assuredly causes the premature failure of pavement systems, thereby resulting in high lifecycle costs (Maupin 2004). Excessive water content in the pavement base, sub-base, and subgrade soils causes early distress and leads to structural or functional failure of pavement if counter measures are not undertaken (Woelfl 1981).

2.4.12 Pavement Design with Drainage

The pavement behaviour with slurry drainage system is crucial for examining widely accepted pavement design procedures for the new construction or reconstruction, overlay, and rehabilitation of pavements (Mathis 1989). Pavement designing ranges from flexible pavements, selection of optimal thickness of various pavement components, rigid pavement design, appropriate joint design, and design of concrete block pavements to rational method of designing the overlay thickness (Baldwin et al. 1987). Pavement design for highway roads is particularly challenging because the cost is always a major factor. Alternative designs and materials can be used (Forsyth 1987; Hauer et al. 2002).

Pavement design procedures include new construction materials and recycled materials, low-temperature fracture parameters of conventional asphalt concrete, asphalt-rubber mixture, service lives of pavement joint sealants, and testing procedures for pavements. The important materials variably include triaxial testing, fatigue response of asphalt concrete mixtures, rut susceptibility of large stone mixtures, visco-elastic behaviour of asphalt concrete, field impregnation techniques for highway concrete, moisture content in PCC pavements, and back calculation of pavement layer modules (Hansen 1998).

2.5 PAVEMENT DRAINAGE CRITERIA COMBATING MOISTURE

Because of saturated flow conditions, two different approaches are typically considered for the hydraulic design of a pavement system: the steady-state flow and time-to-drain conditions (Pratt 1997). However, estimating the design rainfall rate and rainfall portion that enters the pavements complicates the application of steady state analyses. Therefore, engineers nowadays prefer the time-to-drain approach (Sharpe 1991). This approach is based on flow entering the pavement until the aggregate base course is saturated. After saturation, the excess runoff does not enter the pavement section and simply runs off the pavement surface. After precipitation, the base will drain to a drainage system (Rutkowski et al. 1998). This approach drains 50% of the water, and does not consider the water retained by the effective porosity quality of the material (Shober 1997). Hence, the proper consideration of combating moisture in flexible pavement includes the following (Siew-Ann et al. 2003).

2.5.1 Prevention of Moisture from Entering the Pavement System

Conceptually, the best approach for reducing the detrimental effects of moisture is to prevent moisture from entering the pavement system. An effective means for minimising surface infiltration is by providing adequate cross-slopes and longitudinal slopes to promptly drain water from the pavement surface (Balades et al. 1995). In general, the less time the water is allowed to stay on the pavement surface, the less moisture infiltrates through joints and cracks. However, moisture enters the pavement system from a variety of sources, and nothing can prevent it completely (Shober 1997). Nevertheless, a proper design can minimise the amount of moisture entering the pavement system.

2.5.2 Provide Moisture-Insensitive Materials

Another means of preventing moisture-accelerated damage is to use moisture insensitive or non–erodible base materials that are less affected by the detrimental effects of moisture (Bachtle 1974). However, although some materials can reduce or delay the detrimental effects of moisture, the moisture-insensitive materials by themselves may not fully address moisture-related problems in pavements that are heavily loaded (Siew-Ann et al. 2003).

2.5.3 Cement-Treated Base (CTB)

In addition to the conventional strength testing for durability, CTB materials are checked for resistance to moisture erosion (Hall 1994). In addition, an aggregate sub-base is recommended to prevent pumping and the loss of fine materials beneath the treated base in areas with adverse site conditions (e.g., high design traffic, wet climates, and high amounts of pumpable fines in the subgrade).

2.5.4 Asphalt-Treated Base

Hot-mix asphalt (HMA) base materials can also be effective in minimising moisture problems in HMA pavements. The stripping of asphalt binders because of many factors, but particularly aggregate characteristics and inadequate film thicknesses, is the major problem with asphalt-treated base (ATB). Therefore, just as with CTB, adequate film thickness of asphalt around the aggregates and quality aggregates are required in ATBs to ensure long-term durability (Hall et al. 2003). The ATB layers should be constructed using high quality aggregates, and the design should be consistent with that of a dense graded HMA base course layer defined in the mechanistic empirical pavement design guide. In general, high asphalt content ensures adequate film thicknesses around the aggregates, thereby increasing resistance to moisture (Highlands 1988).

2.5.5 Open Graded Base Materials

Granular materials with high amounts of crushed materials, low fine contents, and low plasticity may also be used to resist the effects of moisture (Baldwin 1987). These open-graded materials provide better resistance to the effects of moisture than dense-graded materials with high fine contents (Field 1982). First, open-graded materials allow easier movement of moisture through the material, so the layer remains saturated for less time. Second, the reduction of fines implies that there is less material that can be ejected through joints and cracks. However, the stability of these untreated permeable base layers is a major concern because settlement can lead to serious problems and thus must be addressed adequately (Forsyth 1987).

To obtain adequate pavement drainage, the designer should consider three types of drainage systems that include surface, groundwater, and subsurface drainages. The systems are effective for 'free water' and water held by capillary forces in soils but not in fine aggregates, which cannot be drained. All three forms of drainages share a symbiotic relationship and should be considered together in the overall drainage design. Use of subsurface drainage in the pavement structure to reduce moisture-related problems and draining of the water from the pavements is well known (IRC-SP-50 1999).

2.6 HIGHWAY MAINTENANCE

The proper maintenance of highways in the aforementioned drainage situations is of great significance. Maintenance operations can be classified in three groups: Routine maintenance embracing work items such as filling of potholes, and repairing of cracks, which are required to be carried out by the maintenance staff almost throughout the year. Periodic maintenance is also required, which includes covering more extensive maintenance operations such as applying a seal or renewal coat, which are required to be done periodically every few years; rehabilitation; and strengthening, which refers to major restoration or upgrading of the pavement through the reconstruction or application of overlays to rectify structural deficiencies.

NHs play a major part of transport network in every country and their maintenance is an important activity for the highway department. The safety and convenience of traffic on the road are governed to a large extent by the quality of maintenance. The operational economics of road transport is influenced by the degree of maintenance imparted to the highway roads. In developing countries such as India, pavement thickness designs with lower specifications are required to achieve overall economy. The financial resources at the command of a maintenance engineer are always lacking, and it becomes necessary to use the same in the most judicious manner by applying the best engineering practices and managerial skill for smooth movement with the increasing traffic on NHs (Lindberg 2002).

The first step of planning maintenance operation is to evaluate the existing pavement in terms of its physical condition, structural capacity, roughness, and other factors. Therefore, condition surveys are undertaken for the visual assessment of the pavement, which would not only cover the type but also the magnitude of the distress and its location (Vitaliano 1990). In addition, pavement surface evaluation based on riding quality (i.e., highway roads roughness) and skid resistance should form the basis for taking maintenance decisions. Necessary information regarding the routine maintenance needs must be readily available because the maintenance staff members are expected to be continuously updated about the physical condition of the road. However, for periodical renewal requirements or long term maintenance strategy, condition surveys are carried out at a regular frequency. It is also desirable that at least two condition surveys are conducted on each stretch of the road every year, before and after the monsoons (Link 2002).

Secondly, the maintenance operations can be classified in three groups: routine maintenance—embracing work items such as filling of potholes, and repairing of cracks, which are required to be conducted by the maintenance staff almost round the year (Bruzelius 2004); periodic maintenance—covering more extensive maintenance operations, such as applying a seal or renewal coat which are required to be done periodically every few years; and rehabilitation and strengthening, which refers to the major restoration of upgrading of the pavement through reconstruction or applying overlays to rectify structural deficiencies (Hawzheen 2008).

Maintenance operations are classified in two groups below:

- Routine Maintenance: This refers to embracing work items such as filling of potholes, and repairing of cracks, which are required to be conducted by the maintenance staff almost round the year (Jose 2002).
- Periodic Maintenance: It covers more extensive maintenance operations such as applying a seal or renewal coat, which is required to be done periodically every few years (IRC, 1982).

2.7 TRANSPORT DESIGN AND SAFETY

During the last 50 years after the independence of India, the transport system has expanded and improved, and efforts to ensure safety and convenience are being made. The management of transportation or traffic system is becoming difficult with the growth of highways and other roads along with increasing population and vehicles. The road and highway transport is managed by the government of India. The transport department and highway authorities are engaged in a constant struggle to make the system safe and to overcome congestion and maintenance of the roads (Hauer et al. 1997). The importance of transport design safety is growing with the increase in the rates of occurrence of crashes and fatalities.

To solve congestion problems, engineers largely suggest increasing the system capacity. This has proven to be a short-term solution in larger transportation systems (Monsere et al. 2006). The lack of adequate continuous maintenance and effective drainage system overload many roads and highways. The public transport services are inadequate to provide congestion relief, particularly for long highways. At the outset of the 21st century, many components of our transportation system are fast approaching or have already exceeded their design. The vaunted roadway system is suffering from wear and tear because of unexpected high use. Since the era of building, large or substantially enlarged existing systems seem to be at an end except, perhaps, for new transit lines. The major challenges are now the rebuilding of the transportation system and its more efficient and responsible use (Persaud 1993).

The landscaping and plantation along a highway play an important role in providing road safety to users and defining the toe and median of the carriageway; particularly, horizontal sharp curve during the night (Poch 1996). It prevents the glare from headlights of incoming vehicles and controls erosion on the slope of the embankments. Trees along the embankment slopes and near major water bodies play a major role in controlling erosion. Similarly, green cover stabilises steep slopes and high embankment, thus moderating the effect of wind and incoming radiation. Large trees, with thick foliage, provide much needed shade to the glaring hot roads during summer. Historical places may be defined by landscaping and turning as per the existing scenarios (Seeck et al. 2009).

2.8 TRANSPORTATION PLANNING AND OPERATIONS

The planning of transportation facilities is an integral part of civil engineering profession (National Oceanic A.A. 2002). Civil engineers developed the first systematic comparison of urban land use, formulated the methods for forecasting future travel demands, trip generation, trip distribution, mode split, and traffic assignment, and analysed spacing requirements. The role of planning in transportation is vital for strategic or tactical evaluations and predictions of travel demands, land use patterns, and air quality issues for various transportation modes for both passenger and freight movements (Lord et al. 2005). Planning and operating appear most prominently in the field of traffic engineering for surface transportation. However, transportation engineers also confront planning and operating issues in facility management (Mazumdar 2012).

The important political, economic, and social trends have affected the evolution of transportation planning including fiscal austerity as a theme of government policy, changing roles of automobiles, environmental concerns, and changing household characteristics (Miaou 1993). In India, the state transport authorities and NHAI manage the transportation system. The system has improved over the years with computerisation (Ouyang 2006).

2.9 ROAD SAFETY EFFORTS IN INDIA

The theoretical considerations on road safety efforts are essential as the result of increase in accident data. Various efforts to minimise the growth of accidents on Indian roads are as follows: The Government of India has pursued the road safety audit (RSA) on existing and proposed new highways (Hauer 1997) and the Government of India has taken several initiatives, which include the formation of a committee under the chairmanship of Shri S. Sundar, Former Secretary (i.e., MoST) in 2005 to deliberate and make recommendations on the creation of a dedicated body on road safety and traffic management (Hauer et al. 1988).

The Committee subsequently recommended a National Road Safety (NRS) policy, 2007, which was approved by the government in March 2010. The policy covers the following focal points:

- To promote awareness about road safety issues.
- To establish a road safety information database.
- To ensure safer road infrastructure by designing safer roads, encouraging application of an intelligent transport system.
- To ensure fitting of safety features in vehicles at the stage of designing, manufacture, operation, and maintenance.
- To strengthen the system of driver licensing and training to improve the competence of drivers.
- To take measures to ensure safety of vulnerable road users.
- To take appropriate measures for enforcing safety laws.
- To ensure emergency medical attention for road accident victims.

- To encourage human resource development and research and development for road safety.
- To strengthen the enabling legal, institutional, and financial environment for promoting road safety culture in the country.

In addition, the government formed the NRS and State Road Safety councils and District Committees as the apex bodies for road safety established under the Ministry of Road Transport of states or union territories (UTs) (Sunder Committee report 2010). The ministry had requested all states and UTs for setting up the State Road Safety Council and District Road Safety Committees and to hold their meetings regularly so that the right message for curbing road accidents reaches to all concerned and due priority is given to road safety (Small et al. 1989). Most of the states and UTs constituted their respective State Road Councils and District Committees by 2011.

The Central Government took the following steps to further improve road safety for users:

- The government approved an NRS Policy. This policy outlines various measures, such as promoting awareness, establishing road safety information data base, encouraging safer road infrastructure that includes the application of intelligent transport, and enforcement of safety laws.
- The government constituted the NRS Council as the apex body to take policy decisions in matters of road safety. The ministry requested all states and UTs to set up State Road Safety Councils and District Road Safety Committees.

- The ministry adopted a multipronged strategy to address the issue of road safety on the basis of four E’s of road safety that include (i) Education, (ii) Enforcement, (iii) Engineering (roads as well as vehicles), and (iv) Emergency care.
- Road safety was made an integral part of road design at the planning stage.
- RSA of selected stretches of NHs and Expressways.
- Establishment of driving training institutes.
- Tightening of safety standards of vehicles, such use of helmets, seat belts, power-steering, and rear view mirror.
- Publicity campaigns on road safety awareness.
- Refresher training for heavy vehicle drivers.
- Setting up of institutes for driving training and research.
- Establishing the NH Accident Relief Service Scheme for providing cranes and ambulances to states, UTs, or NGOs for relief and rescue measures in the aftermath of accidents by evacuating road accident victims to nearest medical aid centres and for clearing the accident site.
- Enforcement and implementation of various rules and regulations relating to road safety equipment. So far, under this scheme, interceptors were sanctioned for detecting the violation of rules by road users, such as over speeding, drunken driving, lane jumping, and dangerous driving.
- Publicity measures and awareness campaign on road safety.
- Setting up model inspection and certification centres for vehicles. Because of the aforementioned efforts, a slight change was observed in the accident trend and deaths. Additional research is required to correlate highway safety to the maintenance and drainage design of the system.

This chapter highlighted the literature review and theoretical considerations. Focus was given to the importance of drainage system and factors required for improving the design. Furthermore, the maintenance of highways was summarised with special emphasis given to the routine and periodic maintenance, rehabilitation, and strengthening. In maintenance, regular evaluation is required to assess the condition of highway roads. A study on maintenance systems revealed that drainage and surface defects are important factors, which require special attention, apart from the pavement design, to prevent moisture. Finally, for safety and maintenance, the mechanism of transport, design, and planning are essential features to be considered before deciding the research methodology. Hence, highway drainage directly correlates with maintenance and indirectly relate safety and requires a systematic study for identifying necessary features and conditions.

CHAPTER 3
MATERIALS AND METHODS

In this chapter, the primary and secondary data collected from various government websites are provided. To fulfil the objectives of this study, pavement maintenance and safety were undertaken. The study proposed to understand the results, which were obtained by analysing the data for further discussion in view of future considerations and recommendations.

The present research focuses on the highway drainage, maintenance, and safety issues. Because of the rapid increase in traffic and ribbon development along the sides of Indian highways, catering to huge number of vehicles is considered to decide the necessary variables of the perception survey in the semi–structured questionnaire.

Essential data were collected in forms of both primary and secondary information, which were analysed for hypothesising the highway drainage for optimum maintenance and safety (FHWA 1992). The primary information was collected through a survey conducted on the selected stretch of NHs taking random samples in research aspects. The perception survey conducted highlights the maintenance cost of their vehicles, reasons of accidents, drainage systems, and damages to pavements to identify required improvements for the highways. The first half of respondents of the questionnaire consist of mainly highway vehicle drivers. The second half of the survey consisted of detailed interviews of relevant civil engineers and other officials to understand the problem on the present design and to identify features of future economic and safe designs by improving the conventional design execution.

Secondary data collected on highway roads consists of rainfall, accidents, accident deaths, number of vehicles, and annual maintenance cost (Ahuja 2005). These data were collected from different government websites, such as the NHAI, Meteorological Department, and road transport ministry, to obtain relevant information. The study regarding stakeholders perception on highway roads was started with the overview of the study area, that is, Rajasthan. It includes the present economic and infrastructure scenario of roads, investment details, road types, and transportation in SHs and NHs (R. Development core team 2005).

3.1 STUDY AREA

The exact location of the study area situated in Rajasthan is on the highways, at the entry and exit to Jaipur. The perception data of the study area were marked on the GT map represented in Figure 3.1, which exhibits the NHs from Jaipur city, i.e. Delhi to Mumbai (NH-8), Agra to Fathepur (NH-52), Jaipur to Jabalpur road (NH-12). The preliminary study was carried out to identify features and variables of the perception survey on the basis of field data collected by consulting highway technical experts. The brief description on the study area (Rajasthan) includes an economic study, infrastructure, and road transport network, which are mentioned in the next successive section (Economic survey of Rajasthan, 2012). The study data regarding the variables and features are collected in the form of preliminary data, then through an opinion survey conducted through a semi-structured questionnaire enclosed in Annexures A1 and A2.

3.1.1 Brief Discussion on Study Area

The preliminary perception survey was conducted for highways at the entry and exit to Jaipur in Rajasthan. After the independence of India, Rajasthan was formed as a result of integration of several princely states in 1949.It is situated in north-western India and is spread across the border of Pakistan. It has 33 districts with the capital city of Jaipur, which is a well-known tourist place in India. The population of Rajasthan according to 2011 census was approximately 10 crores of which approximately 70% reside in rural areas. A huge portion of the state is covered by the largest Indian desert, the ‘Thar Desert’. The most famous Aravali range runs diagonally from south-west to north-east through its middle territory. The Aravali range splits the state into two geographical zones, desert at one side and a forest belt on the other side. Nearly 61% of the state covers 11 districts and approximately 40% of its population lies in the west of the Aravalis in the Great Indian Desert.

The geographical diversities of the state have made it extremely vulnerable to draught and scary conditions. Approximately 9% of the state falls under the forest zone (ESI 2012). The absence of perennial rivers in northern, western, and central part of the state and the availability of ground water at considerable depths pose serious problems for the availability of drinking water.

Even after several developmental efforts by both state and central governments, Rajasthan is one of the underdeveloped states in India. It has limited resources for its development and depends upon other neighbouring states. The state is culturally rich with a history of loyalty, pride, romance, music, and poetry. It is also famous for textiles, semi-precious stones, and handicraft and traditional colourful art. This state is famous for the forts and palaces, which attract national and foreign travellers. Recently, several famous personalities from films and businesses around the world have started organising events in the beautiful forts and palaces in Rajasthan (Economic Survey of Rajasthan 2012).

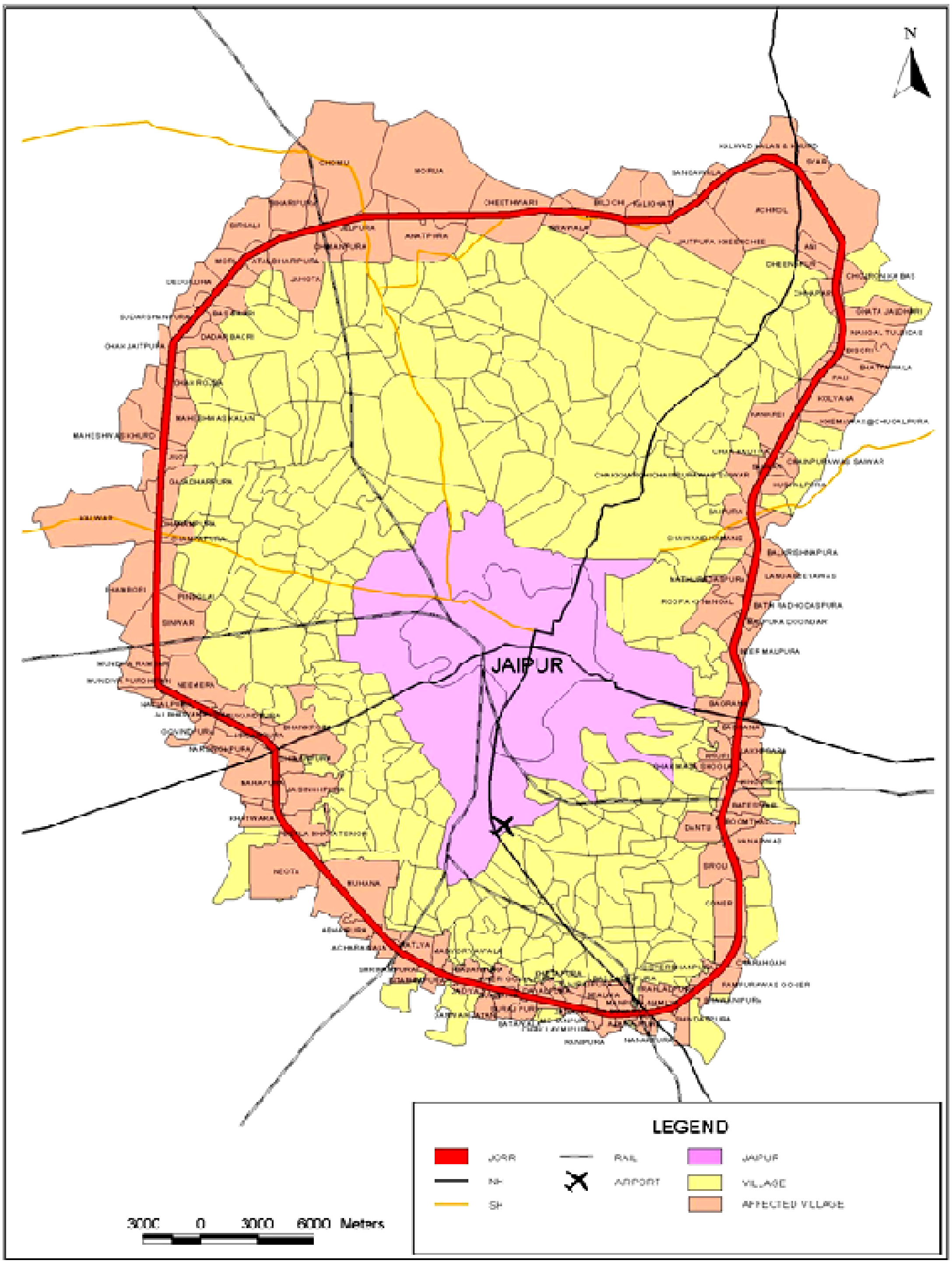


Figure 3.1. Study Area GT Map around Jaipur City (Rajasthan)

3.1.2 Economic Study on the Research Area

The gross state domestic product (GSDP) is the total monetary value of all the final goods produced and services rendered by an economy during a given year, before making any provision for consumption of fixed capital. According to the Economic Survey 2012, the constant GSDP (2004–05) or real GSDP of the state in 2011 was Rs 1960 crore compared to Rs 1780 crore in the year 2010, registering an increase of 9.6% over the previous year. The economy of the state is nearly dependant on agriculture, 22% of the state's GDP is obtained through agriculture. Rajasthan has cultivated areas of almost 20 million hectares but only 20% of the total cultivated area is irrigated. The main crops are food grains, pulses, oilseeds, and sugarcane. The state has emerged as a leading oilseed producer in case of rape, soya-bean, and mustard. The availability of increased infrastructural facilities, financial assistance incentives, and concessions have provided a favourable atmosphere to the state's industrial and mineral activities. The state has recently acknowledged a liberalised industrial and mineral development policy including many simplifications of procedures.

Infrastructure development, such as the availability of power, water, roads, and transport, are being greatly focussed upon so that the state comes up to rank among the few premier states of the country in socio-economic development. In the state, the GDP share of transport and allied sectors was more than 5% in 2010–11. With the extensive increase in the network of rural road in the last 10 years, a tremendous growth is seen in rural areas. In addition to other benefits, education, medical, and health care facilities have increased substantially (ESR 2012).

3.1.3 Infrastructure of Study Area

An integrated network of communication is necessary for rapid economic development. It is an engine of development for agriculture, commerce, transport, education, health, social welfare, and law and order, which improve because of mere availability of good road network. Although the road network carries a larger share of traffic, railways receive the major share of investment, which is almost double than that invested on roads. There have always been an extremely low allocation of resources or funds than that demanded by road and highway planner, which causes poor road specifications and maintenance. In the last 5–6 years, the allocation of funds for roads in the state and central plans have reduced from 9.30% in the first state plan to 6% in the eighth plan and further decreased to 4.64% in the twelfth state plan. In the eleventh plan of the central government, the transport expenditure to total outlays was 7% (Figure 3.2).

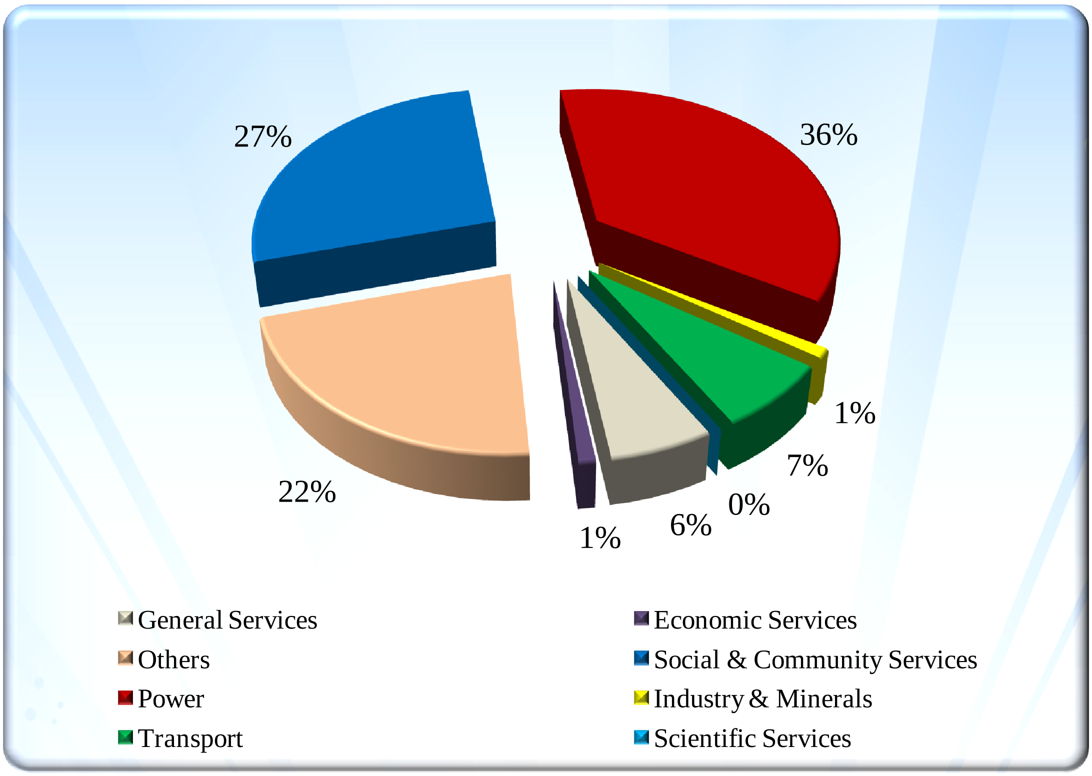


Figure 3.2. Distribution of Expenditure of Eleventh Plan (2007–12)

Figure 3.2 presents a percentage distribution of the expenditure of the eleventh plan (2007–12), which includes 36% for power, 27% for social and community services, 1% for economics services, 6% for general services, 1% for industries and minerals, and 22% for other activities. The Planning Commission approved the eleventh five-year plan of the state of Rs 71700 crore from the total outlay of Rs 31800 crore in the earlier plan period, which was more than double. The transport sector share in the total outlay was approximately 7% as mentioned earlier.

3.1.4 Transport and Road Network System of the Study Area

A healthy transport system is an indicator of economic health and development of a state. All types of development, whether in agriculture, commerce, transport, education, industry, health and social welfare, and law and order, can be improved by a better transport and communication system. An integrated and efficient communication mode is necessary for the rapid economic development of the state (Economic Survey 2012).

The state had a very poor network of road and railways after its formation in 1949. Therefore, it continues to be underdeveloped from the point of view of communication despite providing the much required investment. In the absence of inland waterways and inadequate expansion of railways, roads provide the major infrastructural link. During the plans, focus was on the development of transport and communication infrastructure with a view to open up remote areas of the state with better and more roads for social and economic development (Annual report P.W.D. 2012).

The state is presently making several efforts to strengthen the road network because of which (on 31st March, 2011), the total road length in the state was recorded at 128000 km. The road density in the state was 55.09 km per 100 km^2 at the end of 2009–10 and 55.23 km per 100 km^2 by the end of 2010–11. The number of vehicles in the transport sector has grown rapidly over the last several years. The total number of motor vehicles registered with the transport department of the state was 69.98 lakh until December 2009, which reached 77.86 lakh by the end of December 2010 with a 11.26% increase.

The state road system is largely dominated by village roads. The village road network has received an impetus with the launch of PMGSY in 2000, which has enhanced the road length in the state by more than 90,000 km during the last 10 years (Table 3.1).

Table 3.1. Distribution Of Road Network in Rajasthan

Category	Length (in kms)	Percentage
National Highways	7,334	5.54
State Highways	11,300	8.54
Major District Roads	9,455	7.14
Other District Roads	14,133	10.68
Village Roads	90,061	68.08
All	132,283	

Figure 3.3 demonstrates that approximately 68% of the road network was covered by village roads, followed by 11% of other district roads, 9% state highways, 7% major district roads, and 5.5% NHs as per the total road length.

Although one of the main objectives of the new road policy of the state is to provide connectivity to people and bring the declaration of SHs in the mainstream of the nation's policy, a small share of NHs and SH roads from the overall road network indicated low priority given to highway networks in the state. In the policy document, it was also mentioned that the crust thickness of most of the existing SHs is inadequate to presently cater to the demand of the projected traffic roads. A weak section of SHs must be strengthened as per the design requirement according to IRC in the next 10 years (National Road Statics, 2012).

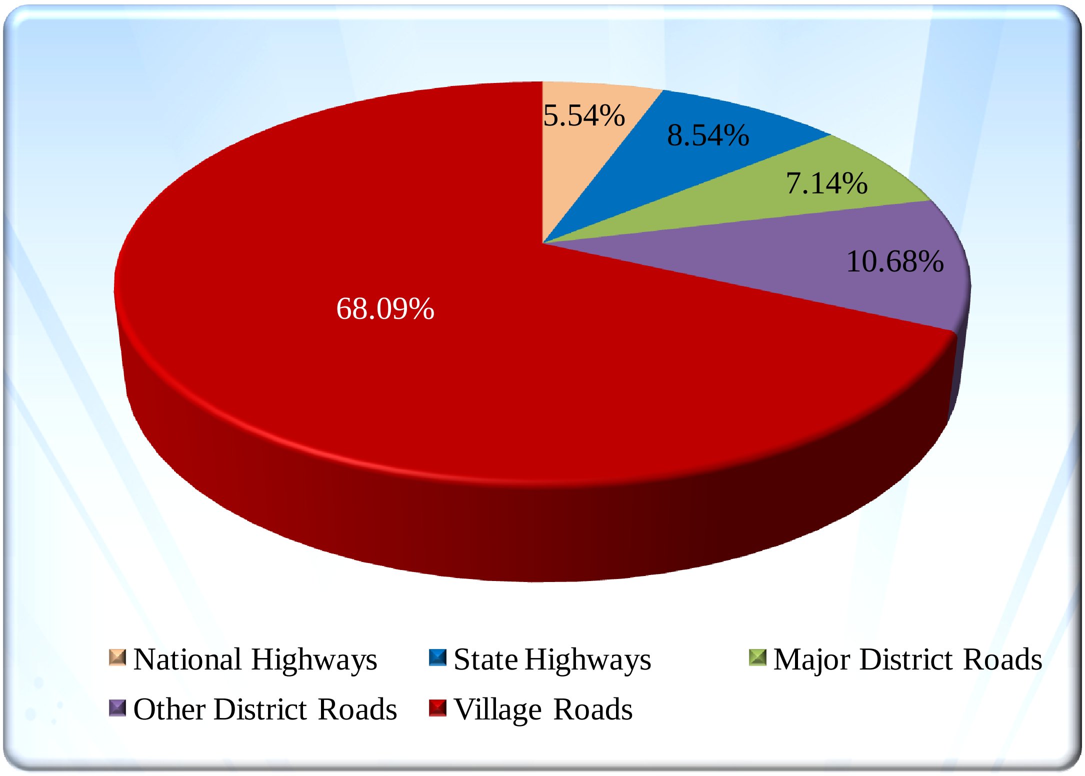


Figure 3.3. Share of lane-wise road length network in Rajasthan

Apart from other roads, the road length of NHs in Rajasthan caters to more traffic and is, therefore, essential for the study considering drainage, maintenance, and safety aspects. Recently, Rajasthan has been in the forefront of successfully implementing a number of road projects by public–private sector partnership.

Rajasthan was the first state to announce a state road policy in 1994 to facilitate the entry of private road sectors. Table 3.2 represents the various types of vehicles registered in Rajasthan. In the state, three-fourth of the total vehicles comprise two wheelers, followed by tractors, cars, trucks, and others. Registration rate so much two wheelers vehicles will create traffic management problem in urban roads /highway already having drainage scarcity (ESR RSRTC 2012).

Several important decisions have been made to improve activities in the field of transportation, which include the computerization of all 74 transport offices, provision of transport facilities to 474 Gram Panchayats, and fitness of transport vehicles through private sector.

Table 3.2. Number of Vehicles by Type

Vehicle	Number	%
Motorised Rickshaws	90	0.00
Two Wheelers	5,707,735	73.31
Auto Rickshaws	101,415	1.30
Tempos	65,014	0.84
Cars	502,952	6.46
Jeeps	221,436	2.84
Tractors	634,473	8.15
Trailers	70,259	0.90
Taxies	75,038	0.96
Buses and Mini-buses	77,000	0.99
Trucks	314,546	4.04
Miscellaneous	15,765	0.20
Total	7,785,723	100.00

3.1.5 SH with Major District Roads (MDR)

SHs provide linkages with NHs connecting district headquarters, important towns, and tourist centres. The present status of SHs shows that a 32-km road length is still not bituminous. The conversion of this road length into a bituminous road must be given top priority and the task must be completed in the next three years, that is, by the end of financial years 2014–15. Of the total 1873-km length of SHs, the carriageway width of the 7617-km road length is less than 2 lanes (7 m). This road length should be widened to minimum 2 lanes in the next 10 years, that is upto the end of financial years 2021–22. Presently, 4346 km are sanctioned under mega highways, Rajasthan State Road Development Cooperation, Road Infrastructure Development Company of Rajasthan, and Central road fund. From the remaining 3791 km, 3000 km will be widened under various schemes and 791 km are likely to be declared NHs in next 10 years.

With the construction of new highways, SHs, MDRs, and mega highways and the development of new industrial areas or zones, new important routes have developed and traffic intensity on some routes have decreased. Hence, redefining the category of roads is necessary. The total length of MDRs is less than that of the SHs, which indicates that new MDRs must be declared for which uniform policies, such as SHs, will be those routes that pass through at least three districts and connect at least two district headquarters, four tehsil headquarters, or four industrial areas. The minimum traffic intensity on the half of this length should be 2000 PSU. The MDRs will be those routes, which connect at least two tehsil headquarters or two industrial areas in the district. The minimum traffic intensity on half of this length should be 1000 PC (Annual report PWD 2012; NHAI 2012).

3.2 NHs

The state has 30 NHs of the total length of 7333 km. Of these, the 2898-km length highway has been transferred to NHAI for development under the NHDP and 118 km for development by MORTH, New Delhi. Approximately 159-km length of the highway is maintained by local bodies or other state agencies and 70-km length is under different BOT projects. The remaining 3401 km is maintained by the state, 757-km length is newly declared NH and is still not entrusted to any agency. Furthermore, Table 3.3 indicates that the total highway road length of 7403 km, mainly has two and four lanes by mentioning maintenance authorities.

Figure 3.4 illustrate more than half of the NH network includes by two lane roads and approximately one-quarter includes 4-lane highway roads in the state. The intermediate and single lanes cover approximately one-tenth of the total highway road length.

Table 3.3. Distribution of NH road network in Rajasthan

Maintenance Authority	Length (in kms)
NHAI	2898
MORTH	0118
Local Bodies/State Agencies	0159
BOT Projects	0070
State Rajasthan	3401
Newly Declared NH	0757
Total	7403

Figure 3.4 represent the lane-wise status of NHs in Rajasthan in which approximately 54% highways are two-laned, followed by 24.4% that are four-laned, 10.5% are intermediate, 9.5% are single-lane, 1.2% six-laned, and 0.4% have missing links.

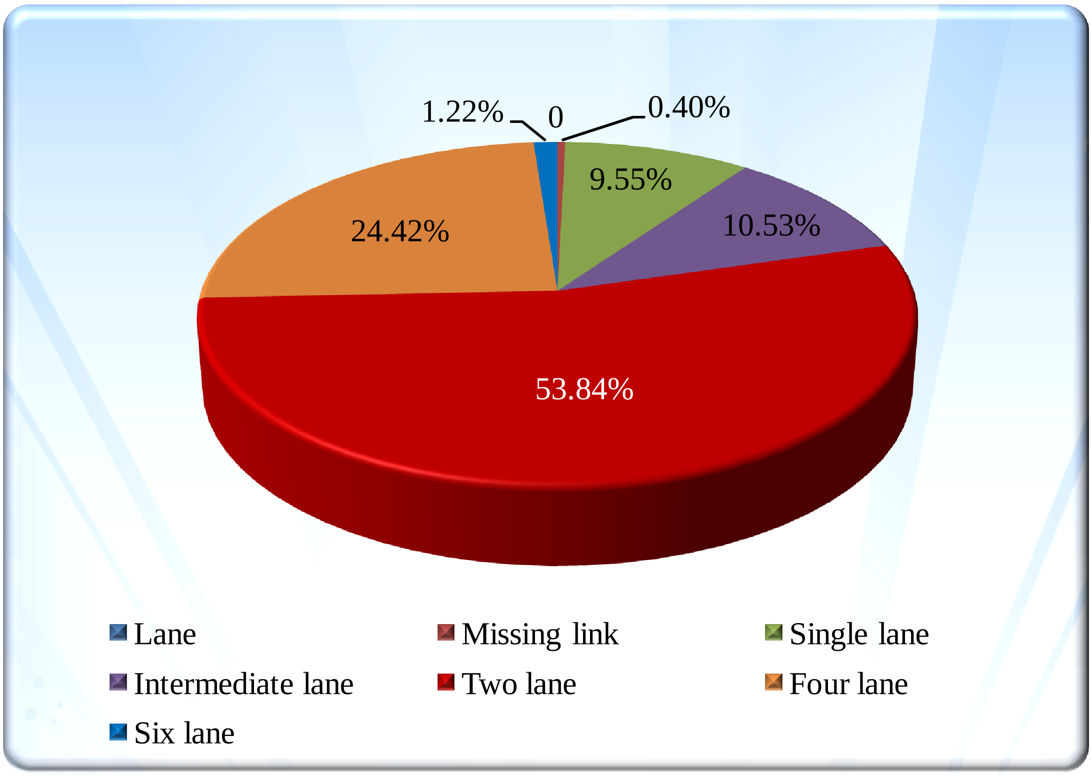


Figure 3.4. Lane-Wise Share of NH Status in Rajasthan

3.3 SURVEY QUESTIONNAIRE IDENTIFICATION

The various influences and deficiencies noticed during the inspection of highway roads were included in the questionnaire and interviews to prove the hypothesis regarding variables on highway drainage, maintenance, and safety.

The variables chosen are related to the highway design with good and bad features of highway drainage, maintenance, and traffic problem, which are further related to highway safety. As per the requirement of drainage, maintenance, and safety conditions, essential variables were introduced. Figure 3.5 depicts the flow chart of the perception survey features.

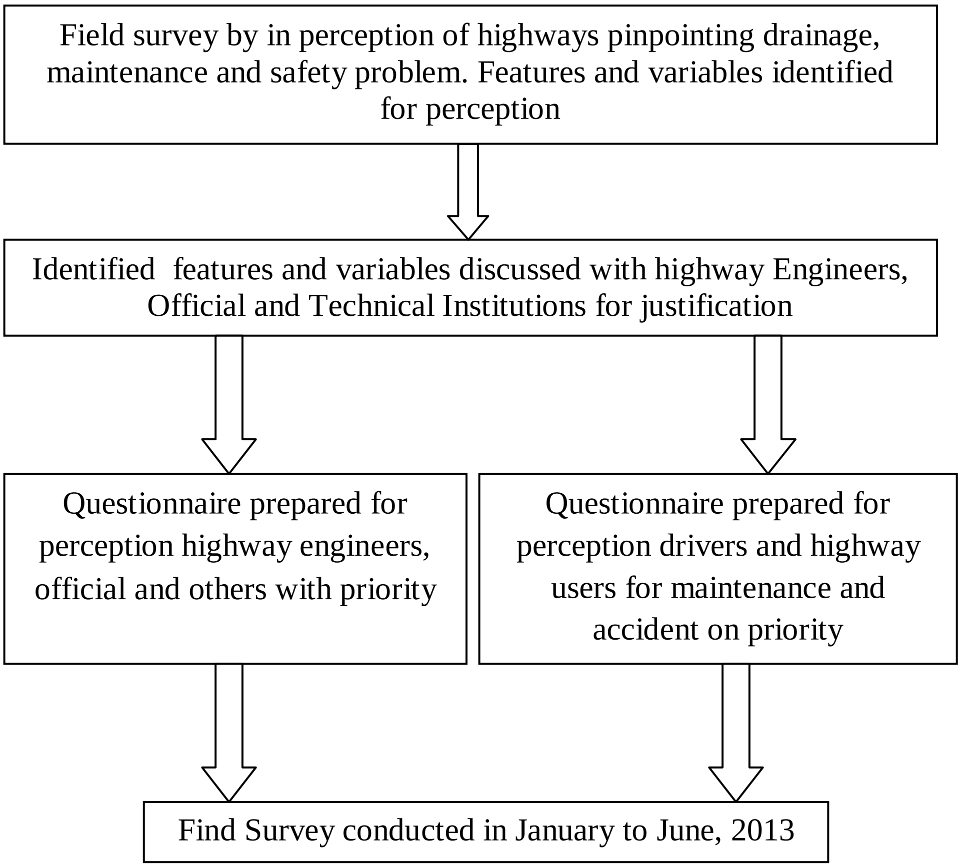


Figure 3.5. Flow Chart for Survey Features

In addition, informal discussions were held with highway engineers and other workers to prepare questionnaires regarding poor designs and lack of maintenance and safety of highway roads, such as horizontal and vertical curves, which must be essentially checked to ensure adequate super elevation. Transition lengths should be provided at the curves for adequate sight distance. Furthermore, crash barriers should be provided on embankments whose height is more than 3.0 m, and road studs should be installed at all junctions. Moreover, lane marking, 'STOP' line markings, directional arrows, and pedestrian markings should be present at all the junctions, and adequate vertical clearances must be provided under all the flyovers and vehicular underpasses.

3.4 PRIMARY DATA OF THE SURVEY

This section highlights the two types of surveys conducted: One with highway-related officials, engineers, and other technical people. The second section is devoted to highway vehicle driver's perceptions as per the questionnaire.

The brief contents of the survey are variables related to highway drainage, maintenance, and safety issues, as well as good and bad features related to highway safety. On the basis of existing data available in government website regarding study variable fixed and introduced for data collected after that statistical analysis is conducted to understand the problem.

The questionnaire was based on highways connecting Jaipur and an interviews were conducted for 920 individuals consisting of almost equal proportions of highway engineers, highway officials, and others (including technical students), from January to May 2013. Furthermore, correlation and factor analyses were used to identify the important factors and relationships among the various aspects such as variables of research objectives concerning highway maintenance and safety related to drainage conditions.

3.4.1 Perception of Highway Officials and Persons

The questionnaire includes the following details in brief: most common features, variables, and conditions considered in the research, which were earlier identified by field observations. Table 3.4 presents the distribution of various respondents' opinions, which include 300 highway engineers, 340 highway officials and 280 other respondents.

Table 3.4. Distribution of Samples

Type	**Frequency**	**Percent**
Highway Engineer	300	32.6
Highway Officials	340	37.0
Other	280	30.4
Total	920	100.0

- Good conditions of different aspects of highway road designs are identified in questionnaire in the order of priority.
- Bad conditions of different aspects of highway road designs are listed priority-wise in the questionnaire.
- The variable of Opinions about the present highway drainage systems are listed in order of priority on the basis preliminary data collected.
- The variable of Maintenance strategy of highway road are listed in order of priority in the questionnaire on the basis of preliminary data collected.
- Main suggestions to improve problems on highways different traffic conditions are listed priority-wise in the questionnaire on the basis preliminary data collected.
- Furthermore, provisions, if any, for an alternate design for improving the present highways, safety, and maintenance conditions have been identified in the questionnaire on the basis preliminary data collected. Figure 3.6 presents various features and variables included in the survey with statistical analysis methods.

3.4.2 Perception of Vehicle Driven on Highway

The following factors and conditions, regarding variable selection for the questionnaire, were briefly considered.

- Average monthly expenditure on vehicle maintenance and factors affecting vehicle maintenance cost on highway.
- Factors affecting highway maintenance on account of VOC.
- Reasons for accidents on highways, measures to tackle accidents, and direct and indirect impact of accidents.

The primary information was collected through the survey conducted on the selected stretches of NHs with sample of 920 respondents on various aspects in which a perception survey highlighting the maintenance cost of their vehicles, reasons of accidents, drainage systems, damages of pavements, and suggestions for the improvement of the highways systems. The respondents consist mainly of vehicle drivers on highways and roads. In addition, as aforementioned, detailed interviews of the relevant civil engineers and other officials were taken to understand the maintenance, drainage, and safety problems.

The results of the survey conducted around Jaipur city are briefly described as follows.

- Average monthly expenditure for vehicle maintenance.
- The factor concerning vehicle maintenance cost on highways.
- Factor concerning maintenance of highway in terms of VOC.
- Reason for accidents on highways.
- Measures taken to tackle accidents.
- Direct and indirect impact of accidents.

The survey was conducted in January–June 2013 by using a semi-structured questionnaire to understand the features of highway drainage, maintenance, and safety. The results of the survey present opinions of highway users and other relevant people.

3.5 SPSS

The primary survey data identifies important principal variables or components, and a statistical analysis was used to identify the factors of road maintenance and drainage system. The analysis has been done by using appropriate analysis of statistical packages such as SPSS, which is briefly explicated as follows:

- SPSS is one of the most popular statistical packages, which can perform highly complex data manipulation by using simple instructions.
- SPSS is frequently used in social science and comprises four windows: data editor; output viewer; syntax editor; and script windows. Data is analysed using the menus and dialogue boxes.
- SPSS graph command was used exclusively and is usually used to create graphics in the field of highway data including histograms, scatter-plots, and regression line.
- The graph command allows changing of axes, adding text, changing colour, font, copying, pasting, and exporting (Statistisches Wiesbaden 2006).

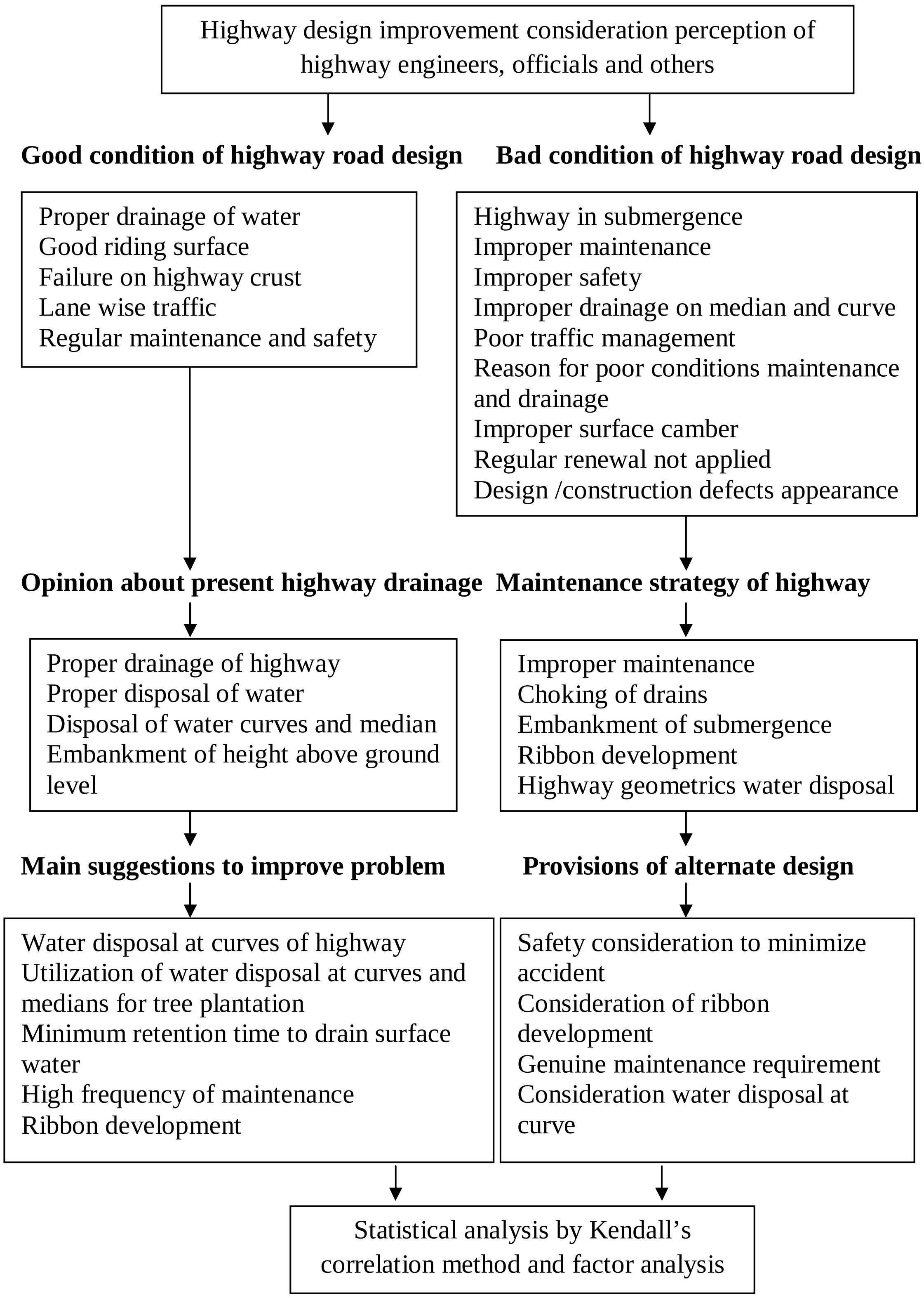


Figure 3.6. Flow Chart Depicting the find Opinion Survey Features and Variables

3.6 SECONDARY DATA COLLECTION

The stretch of NH No. 8 that includes portion of Delhi, Jaipur and Ajmer was selected for the study. The selected highways stretch is constantly busy and comprises four–six lane roads. The road stretch traverses through flat and rolling terrains of mostly agricultural and urban settlement, and further widens to a6-lane road, including a service lane. The location of the terrain and the route maps are shown in the index. This NH is maintained and operated by NHAI under the MORTH under D.F.O.T.

The portion of highway connecting Delhi and Gurgaon is the busiest stretch selected for collecting secondary data and was further analysed to prove the hypothesis of the research.

The collected monthly data during 2008–2011 shows the number of vehicles, accidents, rainfall, and maintenance cost of the highways. According to the data, the number of vehicles increases gradually, and the accident rate and maintenance cost fluctuate. However, because of rainfall, high fluctuation is observed: it is almost nil in some months and considerably high in other months.

3.7 INDIAN ACCIDENT DATA ANALYSIS

In the research methodology, accident data are also analysed to understand highway safety more scientifically to understand the objective of research. The compound growth rate of death and injuries of the Indian scenario accident data was analysed. In addition, road accidents per lakhs of population and per tens of thousands of vehicles are compared in the analysis. The state-wise death and accident rates were compared long with their causes and safety efforts being taken in India are included in the study to understand the factor of safety.

Figure 3.7 represents schematic diagram of the research methodology including the data collection with analysis, showing the essential events.

3.8 FIND SURVEY DATA ANALYSIS METHODS

First a correlation matrix was prepared to examine the association between the variables. Furthermore, the important factors were identified using factor analysis by suitable statistical methods, such as Kendall rank correlation coefficient and factor analysis.

3.8.1 Kendall Rank Correlation Coefficient

The Kendall (1955) rank correlation coefficient evaluates the degree of similarity between two sets of ranks given to a same set of objects. The following formula of the Kendall rank correlation coefficient for computing sampling distribution of ρ.

The Kendall correlation coefficient depends only on the order of the pairs; it can always be computed assuming that one of the rank order serves as a reference point (e.g., for N = 4 elements, it can be assumed arbitrarily that the first order is equal to 1234) (Statistisches Bundesamt 2012). Therefore, for two rank orders, provided on N objects, N different possible outcomes exist (each corresponding to a given possible order) (Siegel 1956).

$$\rho = \frac{1 - 2 \times [d¢(P_1, P_2)]}{N(N-1)}$$

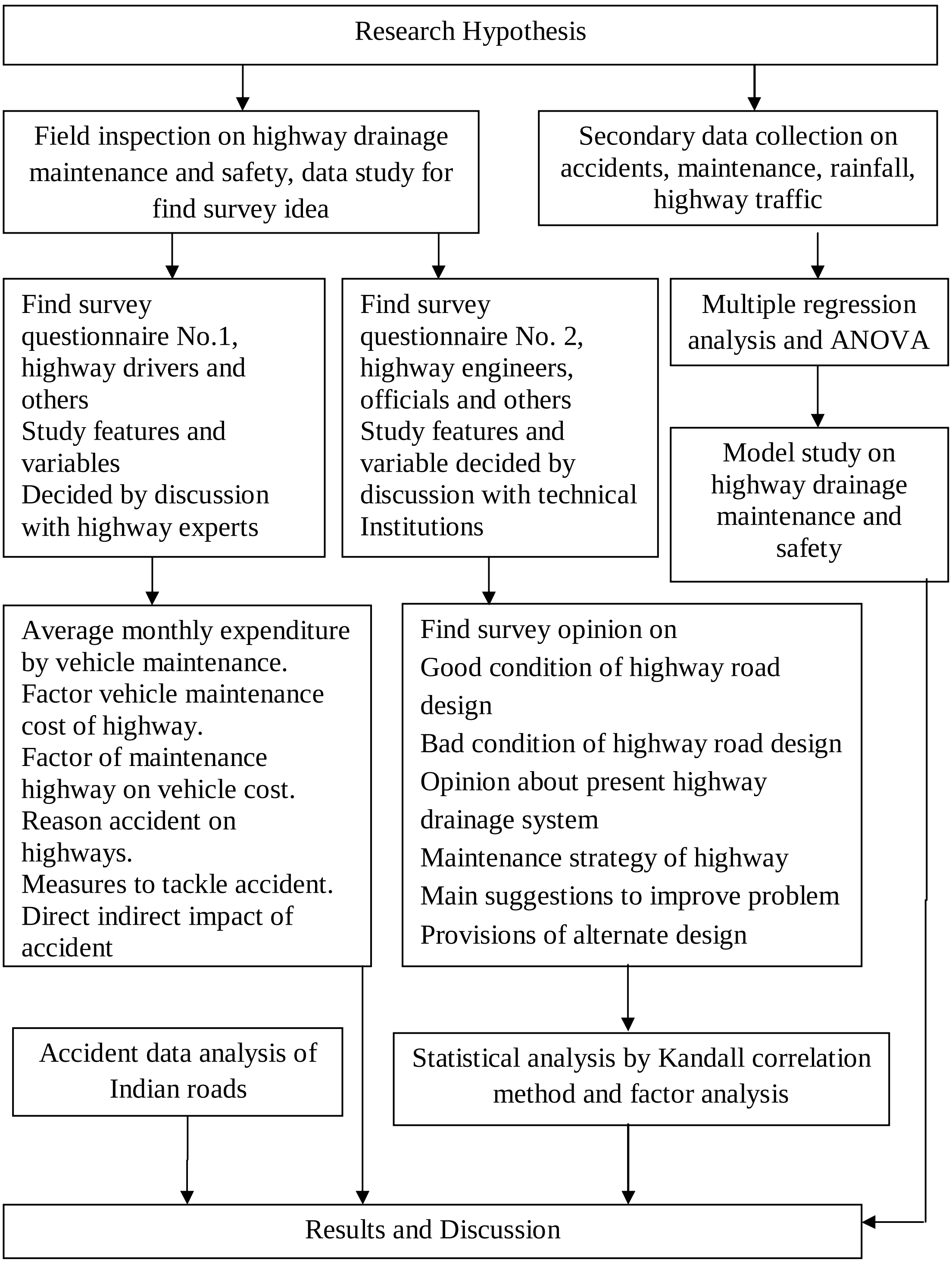


Figure 3.7. Schematic Flow Diagram of the Research Methodology

3.8.2 Extensions of the Kendall Coefficient

The Kendall rank order coefficient depends on a set distance, and is easily generalised to other combinatoric structures such as weak orders, partial orders, or partitions. In all cases, the idea is similar: first, the symmetric difference distances between the two set of pairs representing the binary relation are computes, then this is normalised to take values between −1 and +1.

3.8.3 Factor Analysis

In the sense of exploratory factor analysis, it is a statistical technique for data or variable reduction. It reduces the number of variables in an analysis by describing linear combinations of variables that contain most of the information and admit meaningful interpretations (Statistisches Bundesamt 2012). The important factors of good and bad features of the present highway design include poor conditions of maintenance and improvement of present highway design or system, which are identified using factor analysis. The factors must have an Eigen value greater than zero to be retained and identified by their positive loading factor (Washington et al. 2003).

The following definitions are includes in this study's factor analysis:

- Eigen value: An Eigen value is the variance of the factor.
- Difference: implies the differences between the current and following Eigen value.
- Proportion: refers to the proportion of variance for the factor.
- Cumulative: refers to the cumulative proportion of variance, which is accounted for the current factor and for all the previous factors.

- Factor Loading: refers to the orthogonal solution that represents how the variables are weighted for each factor with the correlation between the variables and the factor.
- Uniqueness: refers to the proportion of the common variance of the variable not associated with the factors. Uniqueness is equal to 1: communality.
- Rotated Factor Loadings: denote the factor loadings for the varimax orthogonal rotation and represent how the variables are weighted for each factor with the correlation between the variables and the factor. A varimax rotation attempts to maximise the squared loadings of the columns.

The ‘estat’ common command is a post estimation command that displays the correlation among the factors of an oblique rotation (Statistisches Bundesamt 2006).

3.9 SECONDARY DATA ANALYSIS WITH ANOVA

The common statistical method ANOVA and the multiple regression analysis were used to analyse secondary data for validating primary research results.

In the study multiple regression analysis was used to examine the factors of road safety. For this, the accident data were used as dependant variables, which include rainfall (proxy for environment and road damage, which is main cause of accidents), maintenance cost (improper maintenance leading to pot holes, absence of caution board on the road, etc.), and the number of vehicles (congestion and more vehicles on the road leads to more accidents due to rash driving and other reasons).

3.10 ANOVA

One of the most commonly used statistical techniques at the Stats II level is analysis of variance (commonly known as ANOVA). The name has the word variance in it, and the technique functions by using variances. Analysis of variance is all about examining the amount of variability in a dependant (response) variable and attempting to understand from where the variability occurs. ANOVA can be used to compare several independent variables regarding some quantitative accident variable. The independent variables are fixed to compare and constitute different groups such as maintenance cost, number of vehicles, and rainfall data. ANOVA is particularly suitable for situations involving an experiment (Hays 1973).It is a statistical process performed in six steps by checking conditions, setting of hypothesis, f-test, making conclusions, checking fitness data, and using chi-square test. These steps are briefly described as follows:

Step One: Checking the Conditions

This is to ensure all necessary conditions.

Step Two: Setting up the hypotheses

The secondary data means can be deemed equal to each other. The null hypothesis for ANOVA is that all the secondary data means are equal.

Step Three: F-Test

Step three of ANOVA comprises the collection of the data, including desired random samples, one from each variable.

Three major steps are used to complete the F-test in ANOVA:

- Break down of the variance of *variables* into sums of squares.
- Find the mean sums of squares.
- Put the mean sums of squares together to form the F-statistic results.

Step Four: Conclusions from ANOVA

On completion of the F-test, determination of F-statistic is the next step of ANOVA: it includes concluding the hypothesis test of the k variable means, and comparing of the F-statistic to the corresponding F-distribution with (k – 1, n – k) degrees of freedom to see where it stands and conclude as per the data analysis (Statistisches Bundesamt 2012).

Step Five: Checking the fitness of the ANOVA Model

It is necessary any other model, fitness with how well the ANOVA model fits before its results with confidence. In the case of ANOVA, the model basically boils down to a treatment variable with an error term. To assess how well that model fits the data, the values of R^2 are predicted and R^2 is adjusted on the last line of the ANOVA output. Multiple correlation coefficients are obtained between the deserved and predicted (Statistisches Bundesamt 2006).

Step Six: Chi-square test

If the two variables are categorical, then a chi-square test is used to examine relationships. The chi-square test looks for relationships between two categorical variables. If two categorical variables do not have a relationship, they are termed as independent. Dependant variables interact with each other (Washington et al. 2003).

- The study collected data tabulated it in a two-way table.
- The numbers represent the observed cell counts.
- Set up of null hypothesis, Ho: either variable is independent; and the alternative hypothesis, Ha: or variables are dependant.
- Calculation of the expected cell counts under the assumption of independence.

- The expected cell count for a cell is the total times rows and which are column divided by the grand total.
- Check the conditions of the chi-square test before proceeding; each expected cell count must be greater than or equal to five.
- Figure the chi-square test statistic.
- The statistic determines the observed cell count minus the expected cell count, squares the difference, and divides it by the expected cell count. Follow these steps for each cell, and add them all.
- Look up test statistic on the chi-square table and determine the *p*-value.
- If the result is less than the predetermined cut-off (the α level), usually 0.05, reject Ho and conclude dependence of the two variables.

If result is greater than the α level, d not reject Ho; the variables cannot be deemed dependant. (Washington et al. 2003).The chi-square test has one main condition that must be met to test for independence on a two-way table:

The expected count for each cell must be at least five, that is, greater than or equal to five. Expected cell counts that fall below five are not reliable in terms of the variability (Statistisches Bundesamt 2006, 2012).

3.11 ANALYSIS OF SAFETY BY USING MULTIPLE REGRESSION METHOD

The secondary research data collected on highway roads requires a suitable solution of runoff pavement surface, considering aspects of future maintenance and safety conditions is examined, using a regression analysis to test the aforementioned hypothesis (Siegel 1956). The pavement surface damaged due to heavy traffic and rainfall requires proper maintenance. The collected data consists of maintenance cost, vehicle numbers, and rainfall as independent factors and accidents as dependant factors, which were examined for the research by using regression analysis.

Use of multiple regression to analyse the road safety of highway projects.

Multiple regression analysis was used to identify the regression result by considering accident data as a dependant variable and rainfall (proxy for environment and road damage, which is main cause of accidents), maintenance cost (if maintenance is not proper, it will lead to pot holes on the road and increase VOC), and the number of vehicles (congestion on roads, rash driving, and other reasons also cause more accidents) as independent variables (Statistisches Bundesamt 2006).

A number of other factors may contribute to the risk of an accident including vehicle design, speed of operation, road design, environmental factors, and human errors. Because the data on these indicators is not readily available, we were not able to include this in the analysis. The regression model can be represented as follows:

$$A\ i = \alpha + \beta_1 V_i + \beta_2 R_i + \beta_3 M_i + e_i$$

where,

The dependent variable is as follows:

A= Number of monthly accidents (in lakh)

The independent variables are as follows:

V=Number of vehicle monthly data (in lakh)

R=Rainfall monthly data (in cm)

M=Maintenance cost monthly data (in lakh) i= time period; 1–48 month data (January 2008–January 2012)

e_i=error terms

Assessing the fit of multiple regression models

For selecting any model, the fit of each model being considered must be assessed to be built into the process on the most popular ones: R^2 (simple linear regression only), R^2-adjusted.

R^2 represents the percentage of the variability in the values explained by the model. It's value is between 0% and 100% (0 and 1.0). In simple linear regression, a high value of R^2 implies that the line fits well, and a low value implies that the line does not fit well. For multiple regression analysis, add more variables (no matter how significant); the value of R^2 increases or remains the same, that is, the value does not decrease, thus resulting in an inflated measure of how well the model fits. Of course, statisticians have a fix for the problem, which leads to the next item on the list (Hays 1973).

R^2-adjusted takes the value of R^2 and adjusts it downward according to the number of variables in the model. The higher the number of variables in the model, the lower will be the value of R^2-adjusted compared to the original R^2. A high value of R^2-adjusted implies that the model satisfactorily fits the data (the closer to 1, the better); typically, 0.70 is considered to be a perfect value for R^2-adjusted, and a higher value is considered more favourable. Thus, R^2-adjusted is used instead of the regular R^2 to assess the suitability of a multiple regression model (Kendall 1955). With every addition of a new variable into a multiple regression model, the value of

R^2 remains the same or increases; It never decreases because a new variable either explains some of the variability in number of data (thereby increasing R^2 by definition), or does nothing (maintaining the initial value of R) (Ram Ahuja 2005). Theoretically, adding more variables into the model just for the sake of getting a larger value of R^2. R^2-adjusted is important because it adds more variables by considering how many variables are already in the model (R. Development Core team 2005). The value of R^2-adjusted can actually decreases if the added value of the additional variable is outweighed by the number of variables in the model, which shows how much or how little added value is obtained from a bigger model. As per the aforementioned methodology, the research data is analysed statistically, and the results obtained for the model study are represented by various Tables and Figure in the next chapter (Washington et al. 2003).

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter projects results obtained by the research and statistical analysis of highway drainage, maintenance, and safety system. The survey perceptions and secondary data collected from study area are represented in Tables 4.1–4.64 and in Figures 4.1–4.27. Tables 4.1–4.39 present the survey perception data of highway managers regarding good and bad features of highway design; opinions about highway drainage features, maintenance strategy, main suggestion for highway design; and suggestions to improve the highway design system or provide an alternate design. Furthermore, Figures 4.1–4.6 derived using Tables 4.6, 4.16, 4.21, and 4.27 present comparative graphical analysis of the results. Tables 4.40–4.45 represent results of highway perception data of drivers and users. Figures 4.7–4.13 derived using Tables 4.40–4.45 present perception data analysis of drivers and users. Table 4.46 presents the accident data of India. Figures 4.14–4.22 exhibit the analysis results of these accident data. The correlation analysis results are presented in Tables 4.47–4.48, which indicate the perception of highway managers by using the Kendall method. In addition, Tables 4.49–4.56 provide the results of the factor analysis of various parameters considered in the survey. Tables 4.57–4.60 show the number of vehicles on monthly basis with maintenance cost, accident data, and rainfall. Figures 4.23–4.26 demonstrate the variation in the secondary data. Table 4.61 provides the annual data for the number of vehicle, accident data, maintenance cost, and rainfall. Lastly, Tables 4.62–4.64 provide the model summary and the variance analysis, including the results of regression correlation coefficient derived from the secondary data to fulfil the objectives of study.

In this chapter, the good and bad features of highway design are provided. These features were decided through the expert opinion survey and preliminary maintenance data of highway drainage, which are ranked according to priority. The necessary observations by respondents have been used to explain traffic and design system of highways. The perception data was collected on major features of highway drainage to understand the problem. In addition, the maintenance strategy of highways was prioritised by perception. The perception data were obtained using stake holders opinion to improve the drainage and maintenance problems in the present highway design system to obtain results of the research. The results of the perception regarding maintenance and safety by highway drivers and others were further analysed to obtain more satisfactory results. Subsequently, factor analysis and Kendall correlation coefficient were used to obtain the final results. The data correctness was examined using chi-square test to prove the hypothesis of objectives. Furthermore, the accident analysis was used to identify safety efforts in minimising accidents. Moreover, the secondary data was analysed using variance and regression model method to obtain regression coefficient results. The correctness of these results was also examined by t-test and F-test, considering that the accident data is an independent variable and the number of vehicles, maintenance cost, and rainfall data are independent variables.

4.1 GOOD FEATURES OF HIGHWAY ROAD DESIGN

Some of the good features of the existing highway design, as perceived by survey people, are given in successive section. The perception results of water drainage, riding surface, highway crust, traffic management and regular maintenance schedule are explained.

4.1.1 Perception on Drainage of Water

Respondents perceived proper drainage as one of the necessary features of a good highway design. Table 4.1 presents priority and percentage of the survey. Approximately 60% of the respondents have given top priority to the proper drainage of water on NHs. This indicates the importance of proper drainage on highways.

Table 4.1. Perception of People on Proper Drainage

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	84.7	43.8	54.6	60.0
2	15.4	25.0	45.5	27.5
3	0.0	18.8	0.0	7.5
4	0.0	12.5	0.0	5.0
Total	100.0	100.0	100.0	100.0

Thus, highway drainage is one of the necessary features for a good highway design. Furthermore, the engineers have given higher importance to this feature revealing the priority of the feature when considering it for NH designing.

4.1.2 Perception on Riding Surface

Table 4.2 presents the survey-related priority and percentage of a good riding surface, which is also an important feature for a good NH road. Approximately 50% of the people in the ‘other’ category have given higher priority to this feature compared to highways officials indicating that is an important feature of NH design.

Table 4.2. Opinion Survey on a Good Riding Surface

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	77.0	50.1	72.70	65.0
2	7.7	31.3	18.2	20.0
3	7.7	12.5	9.1	10.0
4	7.7	6.3	0.0	5.0
Total	100.0	100.0	100.0	100.0

Table 4.2 shows that more than three-fourth of the highway engineers have given importance to this feature in the design of NHs.

4.1.3 Perception on Highway Crust

This feature has not been given high priority by the respondents compare to the previous two features. Table 4.3 shows that approximately 27.50% of the respondents have given top priority to this feature. Approximately one-third of the highway officials have given importance to this feature, which is comparatively higher than others. Even engineers perceive this feature to be of less importance in the highway design.

Table 4.3. Perception on Highway Crust Failure

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	23.10	31.30	27.30	27.50
2	53.8	18.8	18.2	30.0
3	15.4	25.0	27.3	22.5
4	7.7	25.0	27.3	20.0
Total	100.0	100.0	100.0	100.0

The parameters of 'good riding surface' and 'proper drainage of surface water' already included the features of good condition of crust failure in highway system. Hence, the opinion on this parameter is limited.

4.1.4 Perception on Traffic Management

Table 4.4 shows the perception of proper lane-wise traffic management as an important feature of highway traffic operation because the traffic management on Rajasthan's NHs is linked more with flow of traffic. The traffic management is the responsibility of transport officials and police administration; hence, engineers have not given this feature much importance.

Table 4.4. Perception on Lane-Wise Traffic Management

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	0.0	37.5	27.3	22.5
2	30.8	18.8	18.2	22.5
3	38.5	25.0	27.3	30.0
4	30.8	18.8	27.3	25.0
Total	100.0	100.0	100.0	100.0

Highway officials and 'others' also revealed perceptions regarding lane marking:

- Lane marking such as 'STOP' line marking, directional arrows, and pedestrian markings are required at all the junctions.
- Lanes should be marked appropriately in majority of road sections, and pedestrian crossing should be marked near schools, hospitals, town or village limits, bus bays, and VUP and PUP locations for safe movement.

4.1.5 Perception on Regular Maintenance Schedule

Similarly, regular maintenance is an important feature for designing of most NH roads (Table 4.5). Maintenance features are given a high priority by officials compared to that by the 'others'.

Table 4.5. Perception of Regular Maintenance Schedule

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	30.8	37.5	18.2	30.0
2	0.0	6.3	0.0	2.5
3	30.8	18.8	36.4	27.5
4	38.5	37.5	45.5	40.0
Total	100.0	100.0	100.0	100.0

Furthermore, regular maintenance activities are largely implemented by officials and followed by other respondents.

4.1.6 Elaboration of Good Features in a Highway Design System

A summary of good features for highway designs are presented in Table 4.6 on the basis of perceived ranks in Tables 4.1–4.5.

Table 4.6. Summary of Perceived Good Features of a Highway Design System

Design Feature	Engineers (%)		Officials (%)		Others (%)		Average Opinion (%)	Remarks
	Ist Priority	Lower Priority	Ist Priority	Lower Priority	Ist Priority	Lower Priority		
Proper drainage	84.7	15.4	43.8	25	54.6	45.4	44.82	
Good riding surface	77	7.7	50.1	31.3	72.7	18.2	42.83	
Highway crust no sign of failure	23.1	53.8	31.3	25	27.3	27.3	31.26	More than 53% Engineers have given it 2^{nd} priority
Proper traffic management	0	38.5	37.5	25	27.3	27.3	25.94	Many respondents have given it 2nd and 4th priority in order
Regular maintenance schedule followed	30.8	38.5	37.5	37.5	18.2	34.4	34.66	More than 40% respondents have given it 4^{th} priority

Table 4.6 shows the combined first and significant lower priorities of all design features: Proper drainage and good riding surface are observed to be more important features for a good highway drainage system. Good riding surface can only be achieved through the proper maintenance of highways. All the respondents supported this feature. In addition, more number of officials and ‘others’ supported proper traffic management, which is they considered as an essential for safe movement on highways.

Table 4.6 also displays that 53.8% of engineers have given low priority to highway crest design without any sign of failure; however, it is also an essential feature for a satisfactory highway design. More than 38% engineers have given significant lower priority to proper traffic management and regular maintenance schedule to be followed, which can be considered as essential features of highway design system.

Overall, good riding surface and proper drainage are features essential for a good highway design. Regular maintenance schedule, highway crest no sign of failure, and traffic management are also vital features.

Figure 4.1 is derived using Table 4.6 and displays the good features of highway design as obtained through the survey: good riding surface, proper drainage of pavement surfaces, and regular maintenance. The line diagram of the perception survey data graphically indicates the relative importance of good features of a highway design system.

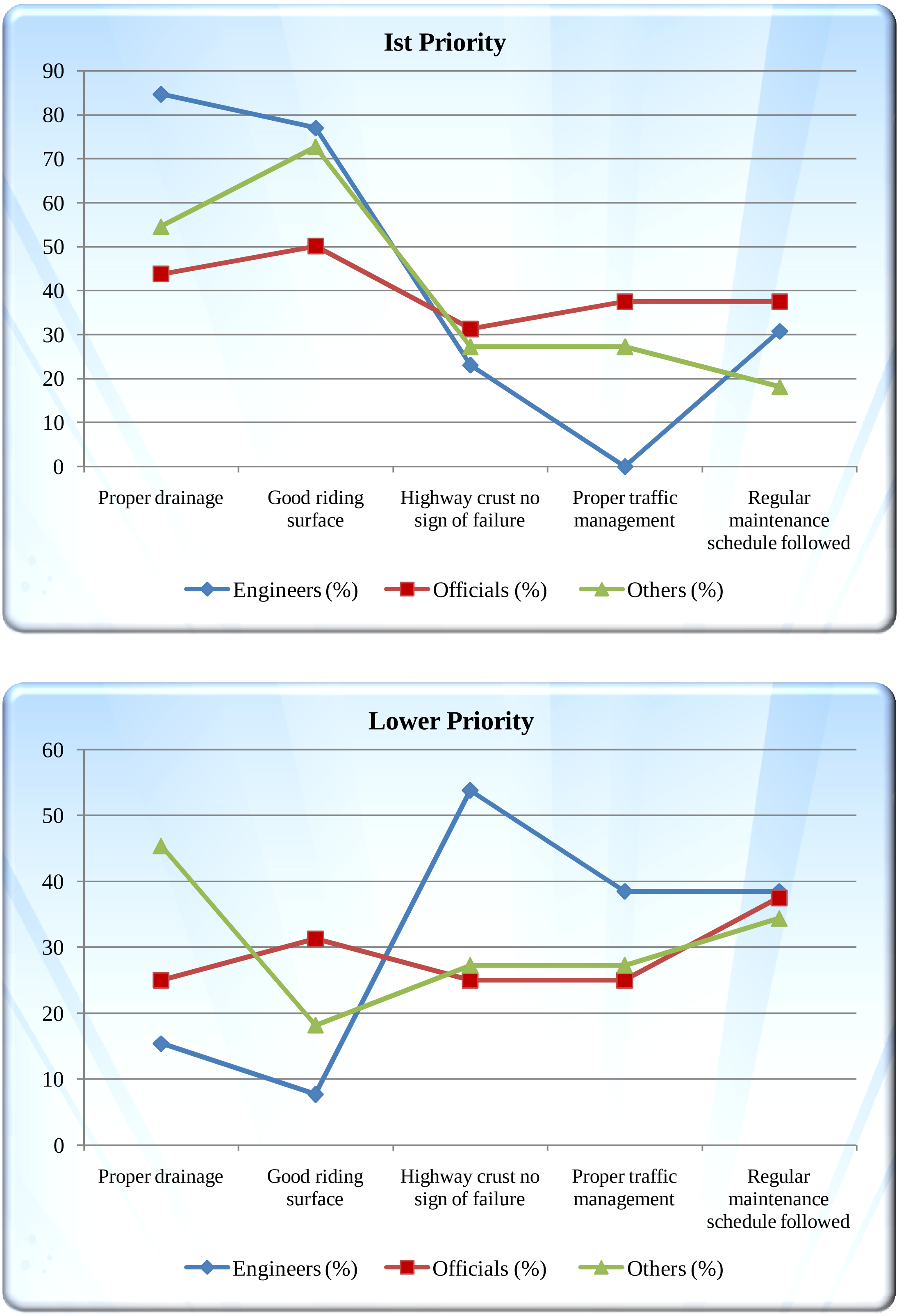


Figure 4.1. Comparative Analysis of Good Features Highway Design

Figure 4.1 Illustrates the opinion survey results, showing the relative high importance for the good features of highway design system. Factors such as proper traffic management, regular maintenance schedule, and highway crust no sign of failure seem less important for a highway design system. According to first priority opinions, more number of respondents have given significant lower priority to proper traffic management. More than 40% of respondents have given significant lower priority to regular maintenance schedule. In addition, many engineers have given second priority to highway crust failure, indicating that it must be included as a good feature of a highway design system. In conclusion, a good riding surface and a proper drainage play a major role for any highway design system, followed by regular maintenance schedule, highway crust design, and proper traffic management, which are unquestionably and imperatively essential features for a hi-tech highway design system. Figure 4.1 also provides a comparison of the priority-wise importance given by respondents for good features of a highway design system.

4.2 BAD FEATURES OF HIGHWAY ROAD DESIGN

The following sections describe the short comings of the present highway system. Features such as highway in submergence, highway maintenance, highway safety, drainage at median and curves, traffic management, drainage maintenance conditions, surface camber, renewal on road surface, and design or construction defects were considered for highway design impacts and assessment.

4.2.1 Highway in Submergence

Because of low height of embankments, highways get submerged during the rainy season. Table 4.7 shows that approximately 65.0% of the respondents perceive that highway road in submergence is the main cause of the bad condition of highways.

Table 4.7. Perception on Highway in Submergence

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	64.3	66.6	64.3	65.1
2	14.3	13.3	21.4	16.3
3	0.0	6.7	0.0	2.3
4	21.4	13.3	14.3	16.3
Total	100.0	100.0	100.0	100.0

Submergence leads to traffic hazard, safety, and maintenance problem.

4.2.2 Perception on Highway Maintenance

Table 4.8 describes that approximately half of the engineers and 'others' have agreed and given first priority to the improper maintenance schedule of NH roads. Officials of NHs slightly disagree because this activity is their main responsibility.

Table 4.8. Perception on Improper Maintenance Schedule

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	50.00	26.60	50.00	41.90
2	14.3	20.0	0.0	11.6
3	28.6	40.0	42.9	37.2
4	7.1	13.3	7.1	9.3
Total	100.0	100.0	100.0	100.0

Therefore, NH officials were not as vocal as engineers regarding the improper maintenance of highways.

4.2.3 Perception on Highway Safety

Table 4.9 presents perceptions regarding highway safety. Approximately 47% officials agree that this feature is a critical parameter for highway design. Highway engineers are neither in favour nor against the proper safety parameter. Majority of the engineers have given lower priority to this feature. Highway safety feature is more related to traffic regulation instead of design or construction.

Table 4.9. Perception on Improper Highway Safety

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	21.40	46.70	14.30	27.90
2	42.9	13.3	57.1	37.2
3	28.6	20.0	14.3	20.9
4	7.1	20.0	14.3	14.0
Total	100.0	100.0	100.0	100.0

4.2.4 Perception of Highway Drainage at Median and Curves

Table 4.10 shows that less than half of the respondents are not satisfied with the drainage conditions of high medians and curves: 57.1% of the engineers, who understand the design part better than others, agree about the improper drainage condition of present highway designs.

Table 4.10. Perception on Improper Drainage at Medians and Curves

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	57.1	40.0	42.9	46.5
2	14.3	33.3	7.1	18.6
3	14.3	6.7	28.6	16.3
4	14.3	20.0	21.4	18.6
Total	100.0	100.0	100.0	100.0

4.2.5 Perception on Traffic Management

The responses are similar to those described in Section 4.2.4 that traffic management has been given lesser priority by the respondents (Table 4.11). It is related more to the flow of traffic because poor maintenance of highway hinders smooth movement of traffic. If these two features are dealt with, the traffic management will be minimised. More number of respondents have given fourth priority to this feature.

Table 4.11. Perception on Poor Traffic Management on Highways

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	28.5	20.0	14.3	20.9
2	7.1	20.0	14.3	14.0
3	14.3	26.7	14.3	18.6
4	50.0	33.3	57.1	46.5
Total	100.0	100.0	100.0	100.0

4.2.6 Perception on Highway Drainage Maintenance Condition

Most of the respondents believe that poor maintenance of highway drainage causes pot holes and patches, which further deteriorate the road condition (Table 4.12). This emerged as one of the crucial features of NH roads, and requires proper attention. This is given first priority by approximately 73.57% of engineers, 58.8% of highway officials, and 71.4% of ‘others’.

Table 4.12. Perception on Poor Highway Drainage Maintenance

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	73.4	58.8	71.4	67.4
2	6.7	29.4	14.3	17.4
3	20.0	11.8	14.3	15.2
4	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0

Hence, poor condition of highway drainage maintenance is relevant factor in highway design.

4.2.7 Perception on Surface Camber

Approximately more than 40% of the respondents agreed that improper surface camber allows stagnant water on pavements (Table 4.13). However, engineers have surprisingly given lower priority to this feature than the ‘others’.

Table 4.13. Perception on Improper Surface Camber

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	33.3	47.1	42.8	41.3
2	6.7	29.4	21.4	19.6
3	46.7	23.5	21.4	30.4
4	13.3	0.0	14.3	8.7
Total	100.0	100.0	100.0	100.0

Even people who are less aware of the technicality in highway design have agreed more that stagnant water on pavement because of surface camber causes traffic movement problem.

4.2.8 Regular Renewal of Road Surface

Table 4.14 shows that most of the engineers and others have given lower priority to regular renewal of road surfaces. However, approximately 41% of highway officials has revealed that road surfaces are not regularly renewed because regular renewal application is part of officials' duty, which is reflected in their responses.

Table 4.14. Perception on Irregular Renewal of Road Surfaces

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	26.6	41.2	35.7	34.8
2	66.7	23.5	28.6	39.1
3	6.7	35.3	28.6	23.9
4	0.0	0.0	7.1	2.2
Total	100.0	100.0	100.0	100.0

4.2.9 Design or Construction Defects on Highway Surface

Table 4.15 points out that 53.3% of engineers and 58.9% highway officials give top priority to design and construction defects that appear on the highway surface. In addition, approximately 35.7% of the others give high priority to design and construction defects.

Table 4.15. Perception of Design or Construction Defects on Highway Surfaces

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	53.3	58.9	35.7	50.0
2	13.3	17.6	35.7	21.7
3	26.7	23.5	14.3	21.7
4	6.7	0.0	14.3	6.5
Total	100.0	100.0	100.0	100.0

Although others do not have much knowledge about highway construction, their responses reflect the importance of this feature.

4.2.10 Elaboration of Bad Features Highway Design System

The summary of the perceived bad features of a highway design system, according to their priority, are enumerated in Table 4.16 on the basis of ranks in Tables 4.6–4.15.

Table 4.16 clearly indicates the combined effect of first and significant lower priorities. It demonstrates that all the respondents favoured poor condition of maintenance and drainage, apart from others, as bad features in a highway design system. Moreover, the respondents favoured improper maintenance schedule. All the respondents have emphasised that highway safety is not proper.

Table 4.16 also shows that more than 40% of officials have given importance to improper maintenance schedule as being a bad feature of highway design system.

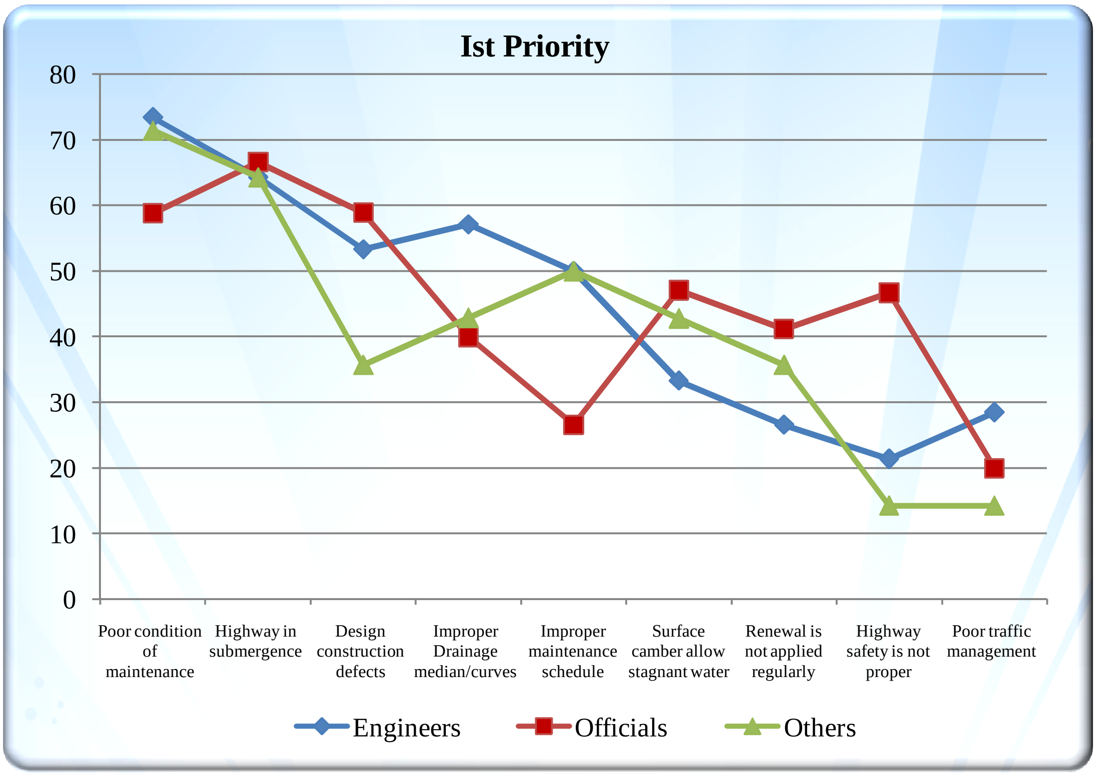
In addition, 66.7% of engineers have given lower priority to road surface renewal, which is not done regularly. Furthermore, 46.7% engineers have given lower priority to surface cambers allowing stagnate water on payment surface. Approximately 50% of engineers have given lower priority to poor traffic management as a bad feature of highway design system.

Table 4.16 further presents the priority wise comparison of the bad features of highway design systems. The features and conditions with higher design priority are as follows:

- Poor condition of highway drainage maintenance
- Highway in submergence
- Highway design and construction defects
- Highway maintenance schedule

Table 4.16. Summarised Perception of Bad Features of Highway Design Systems

Features	Engineers		Officials		Others		All (%)	Remarks
	1st Priority	Lower Priority	1st Priority	Lower Priority	1st Priority	Lower Priority		
Poor condition of maintenance and drainage reason	73.4	20	58.8	29.4	71.4	14.3	44.55	
Highway in submergence	64.3	21.4	66.6	13.3	64.3	21.4	41.88	
Design construction defects appear on surface	53.3	26.7	58.9	23.5	35.7	35.7	38.97	More number of Engineers and officials has given 3rd priority
Improper Drainage at median and curves	57.1	14.3	40	31.3	42.9	28.6	35.7	
Improper maintenance schedule	50	28.6	26.6	40	50	42.9	39.68	
Surface camber allow stagnant water on pavement surface	33.3	46.7	47.1	29.4	42.8	21.4	36.78	More than 46% Engineers has given 3rd priority
Renewal is not applied regularly	26.6	66.7	41.2	35.3	35.7	28.6	39	More than 66% Engineers has given 2nd priority
Highway safety is not proper	21.4	42.9	46.7	20	14.3	57.1	33.73	More than 42% Engineers and 57% other respondents has given 2nd& 3rd priority
Poor traffic management	28.5	50	20	33.3	14.3	57.1	33.86	More than 50% Engineers & others has respondents has given 4th priority



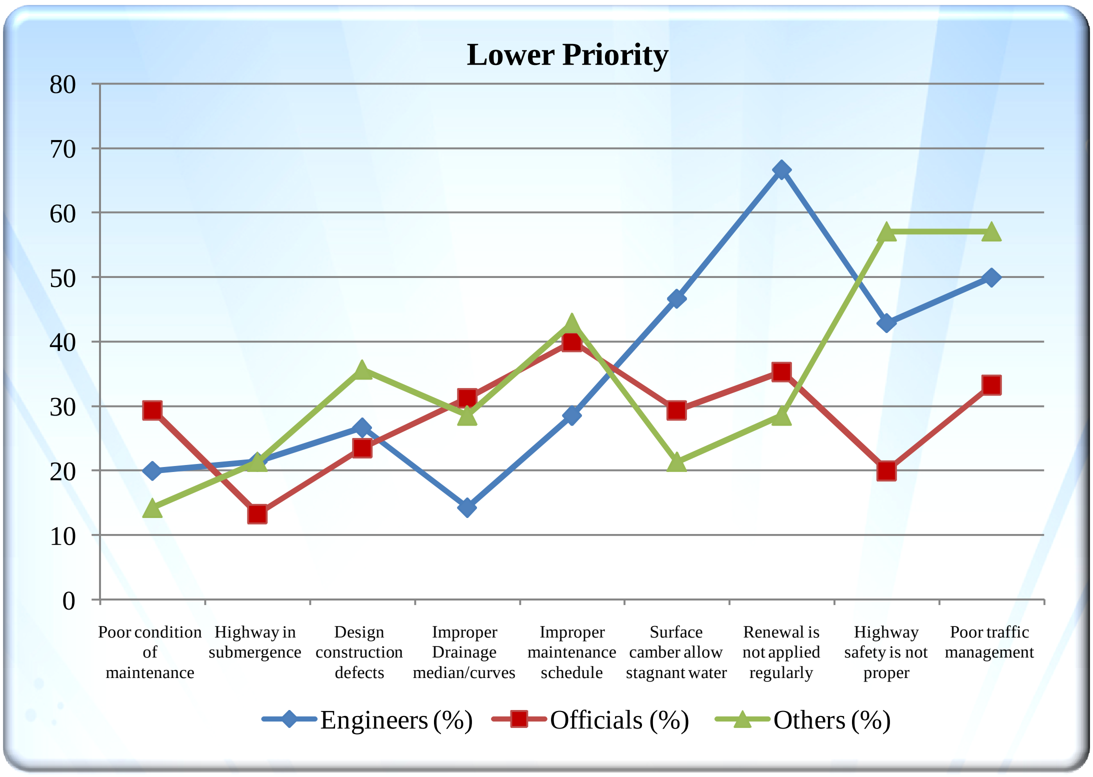


Figure 4.2. Higher and Lower Priorities' Presentation of Bad Features of Highway Designs

Figure 4.2 has been derived using Table 4.16 and illustrates priority-wise perception. Bad features presented for highway design systems are earlier identified in the research methodology. The bar diagram clearly illustrates priorities of bad conditions of highway design systems. The opinion survey shows that factors 1, 2, and 3 are of higher importance. The factors such as traffic management and improper highway safety are given less importance in the bad features according to Figure 4.2. On the basis of significant lower priority data, improper highway safety, irregular renewal, improper maintenance schedule, and surface camber allowing stagnant water on pavement surface are favoured by approximately more than 50% of the respondents. More engineers and other respondents gave significant lower priority to poor traffic management.

Figure 4.2 illustrates the essential bad features of highway design systems on the basis of first and significant lower priorities, which are further analyse during statistical methods.

In conclusion, higher priority is given to the poor highway drainage of pavement surfaces, medians and curves, and submergence. Factors such as improper safety, poor traffic management, irregular renewal, and provision of stagnant water on pavement surface are also essential bad features of a highway design system. The hypothesis is supported by the authentic response provided by many respondents favouring lower priority instead of first prioritised factors.

According to Figure 4.2, 40% officials have given lower priority to improper maintenance schedule. The respondents emphasised surface water allowing stagnate on the pavement surface, improper highway safety schedule, and poor traffic management, which are essential factors to be considered for bad system of highway design.

4.3 PERCEPTION ON HIGHWAY DRAINAGE FEATURES

According to the priority given to good and bad features of highway drainage, the following four perceptions are provided with response about adequacy.

(i) Proper drainage system

(ii) Disposal of surface water

(iii) Disposal of water at curves and medians

(iv) Embankment height above ground level

Photo 1 describes the situation of poor drainage of junction on NH-8, where there is no proper arrangement for disposal of surface water. The spot represented by the photo causes poor conditions for maintenance and safety during rainy days.

Photo 1. Showing Poor Drainage, Maintenance and Safety of NH-8 Junction

The results represented by Tables 4.17–4.20 are described in the next successive sections, and provide respondent opinions on highway drainage features identified on the basis of research methodology mentioned earlier. Perception results on the existence of proper drainage system, proper disposal of water, water disposal at curves, median and embankment height above ground level are explained in the following sections:

4.3.1 Perception on Proper Drainage System

Table 4.17 shows that most of the respondents are satisfied with the subsurface drainage systems. Approximately 53.3% of the engineers are not satisfied with the present drainage system because of future ribbon development. In comparison, 93% of others and 76.5% of the highway officials are satisfied with the present highway drainage system as revealed in this study.

Table 4.17. Perception on Existence of Proper Drainage System

Opinion of respondent	Engineers (%)	Officials (%)	Others (%)	All (%)
Yes	46.7	76.5	92.9	71.7
No	53.3	23.5	7.1	28.3
Total	100.0	100.0	100.0	100.0

4.3.2 Perception on Disposal of Surface Water

Table 4.18 shows that approximately 45.5% of the respondents reported no proper disposal system of water collected through highway side drains. Approximately 61.5% of the 'others' responded that there is no proper disposal system of water on the highway roads. In addition, more than 38.5% of the highway officials compared to approximately 28.6% engineers agreed that water disposal system is not proper.

Table 4.18. Perception on Proper Disposal of Water

Opinion of Respondent	Engineers (%)	Officials (%)	Others (%)	All (%)
Yes	71.4	61.5	38.5	54.5
No	28.6	38.5	61.5	45.5
Total	100.0	100.0	100.0	100.0

4.3.3 Perception on Disposal of Water at Curves and Medians

Photo 2 represents the position of curves on NH-8 without proper surface water disposal. There is no proper system to collect the surface water in storage tanks or harvesting wells in absence of cross drainage. Hence, during rains, pot holes are developed and hinder the smooth movement of traffic.

Photo 2. Poor Drainage due to Surface Water near Curves and Medians on NH-8

Table 4.19 presents the response on the disposal of water at curves and medians. The differences in opinions show that more highway engineers and officials compared to other respondents agree about the disposal of water at curves and medians.

Table 4.19. Perception on Disposal of Water at Curves and Medians

Opinion of respondent	Engineers (%)	Officials (%)	Others (%)	All (%)
Yes	71.4	53.8	46.2	54.5
No	28.6	46.2	53.8	45.5
Total	100.0	100.0	100.0	100.0

4.3.4 Embankment Height above Ground Level

According to Table 4.20, 63.6% of the respondents said that embankment height is not adequate. The responses are almost similar for all the respondents, that is, engineers, highway officials, and others.

Table 4.20. Perception on Embankment Height above Ground Level

Opinion of respondent	Engineers (%)	Officials (%)	Others (%)	All (%)
Yes	42.9	30.8	38.5	36.4
No	57.1	69.2	61.5	63.6
Total	100.0	100.0	100.0	100.0

The priority-wise highway features enumerated according to the perception survey in Tables 4.17–4.20 are presented in Table 4.21. The table is derived using the consolidated features for highway drainage system.

Table 4.21. Consolidated Perception Data for Highway Drainage Systems

Priority	Features	Engineers (%)	Officials (%)	Others (%)	All (%)
1	Proper drainage system	46.7	76.5	92.9	71.7
2	Proper water disposal pavement surface	71.4	61.5	38.5	54.5
3	Disposal of water at curves and medians	71.4	53.8	46.2	54.5
4	Embankment height above G.L.	42.9	30.8	38.5	36.4

Figure 4.3 displays the analysis of opinions about various features of the present highway design to understand the research hypothesis. The graph clearly indicates that officials and others give higher priority to the proper disposal of

pavement water and curves, whereas engineers give higher priority to a proper drainage system.

The proper drainage system itself includes the disposal of water from pavements and curves. Hence, scientifically, opinions of engineers must be considered in highway designs. More than half of the respondents are in favour of proper drainage system with disposal of highway surface water.

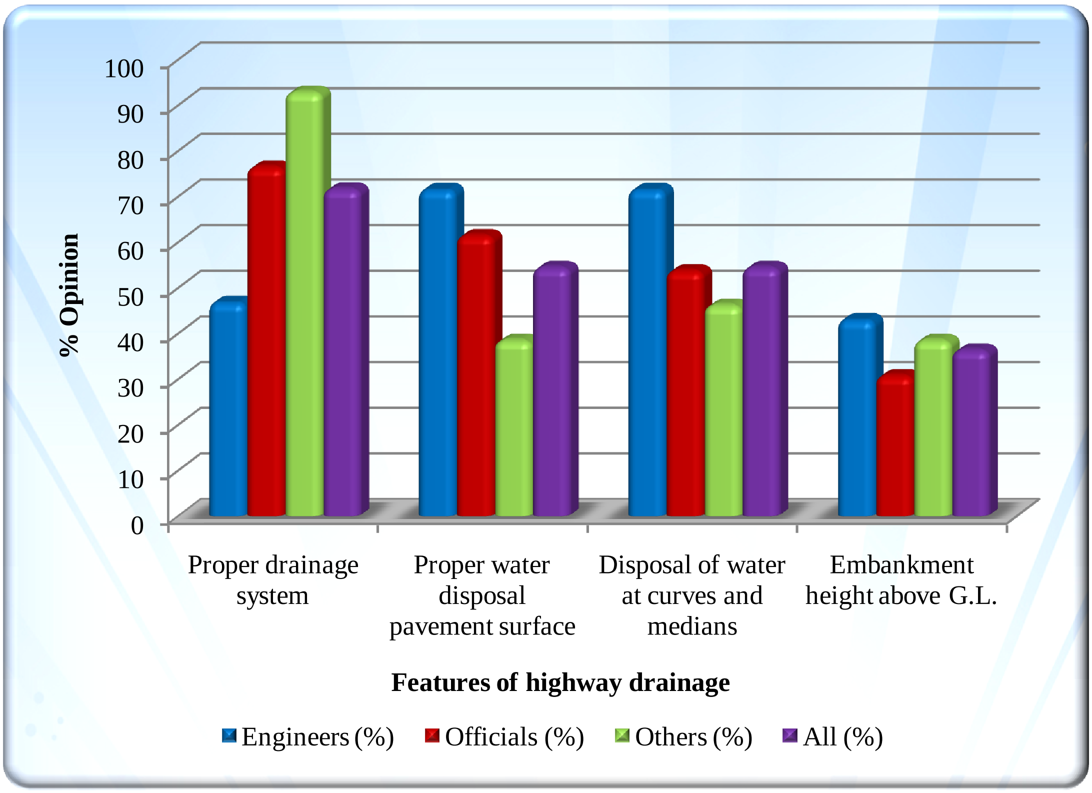


Figure 4.3. Perception Results about Present Highway Drainage System

4.4 MAINTENANCE STRATEGY OF HIGHWAY ROADS

The survey results on highway maintenance with respect to highway drainage system are enumerated priority-wise in following sections. The perception of respondents on highway maintenance, on the basis of features such as choking of drains, embankment in submergence, ribbon development on highway, highway geometric, and disposal of water are explained.

4.4.1 Perception on Maintenance

Table 4.22 demonstrates that approximately 30.2% of the respondents reported that proper maintenance should be given top priority for the highway road. The responses are almost similar for most respondents, that is, engineers and highway officials, but not 'others', who gave higher priority on the basis of upper and lower rank.

Table 4.22. Perception on Improper Maintenance

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	30.8	23.5	38.5	30.2
2	15.4	23.5	15.4	18.6
3	30.8	23.5	0.0	18.6
4	0.0	17.6	46.2	20.9
5	23.1	11.8	0.0	11.6
Total	100.0	100.0	100.0	100.0

Hence, form the point of view of highway users, comparison of opinions of Table 4.12 and 4.22 indicates the importance of highway drainage condition and maintenance on highways.

4.4.2 Choking of Drains

Table 4.23 depicts that almost all engineers and official give higher priority to choking of drains. Because this is part of officials duty (i.e., clearing the choked drains), they gave it first priority.

Table 4.23. Perception on Choking of Drains

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	15.4	58.8	30.8	37.2
2	46.2	5.9	23.1	23.3
3	15.4	11.8	23.1	16.3
4	15.4	5.9	7.7	9.3
5	7.7	17.6	15.4	13.9
Total	100.0	100.0	100.0	100.0

4.4.3 Embankment in Submergence

Table 4.24 shows that more than 20% of the respondent's first priority is for the removal of the submergence of embankment. Approximately 53% of the highway officials have given this problem lower priority (i.e., 2nd, 3rd), followed by others (46%) and engineers (31%). This concludes that embankment in submergence must be given second priority.

Table 4.24. Perception on Embankment in Submergence

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	23.1	23.5	15.4	20.9
2	7.7	29.4	30.8	23.3
3	23.1	23.5	23.1	23.3
4	38.5	11.8	0.0	16.3
5	7.7	11.8	30.8	16.3
Total	100.0	100.0	100.0	100.0

4.4.4 Ribbon Development Along Highway

Photo 3 exhibits the situation of increase in ribbon development along NH-8. From the picture, no consideration of a proper surface water disposal is observed. This results in poor maintenance and safety during rainy days.

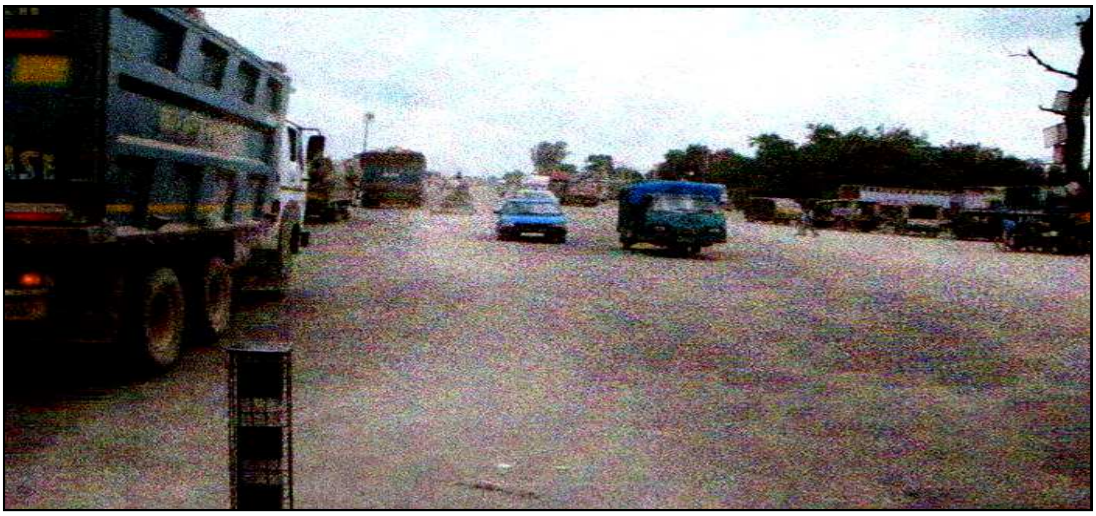


Photo 3. Poor Drainage Due to Ribbon Development on NH-8

Table 4.25 shows that the highway managers response on ribbon development along the highway has mixed results. On one hand, approximately 32.6% of respondents have given lower priority to ribbon development and 18.6% of respondents have given top priority to this activity.

Table 4.25. Perception on Ribbon Development Along Highway

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	23.1	17.6	15.4	18.6
2	23.1	23.5	23.1	23.3
3	15.4	11.8	23.1	16.3
4	30.8	29.4	38.5	32.6
5	7.7	17.6	0.0	9.3
Total	100.0	100.0	100.0	100.0

Although, it differ across type of respondents, with engineers have given more importance, officials have given lower importance and other commuter response is equally divided.

4.4.5 Highway Geometrics Disposal of Water

Table 4.26 shows that approximately one-third of the engineers give first priority to improper highway geometrics such as the disposal of water. This is similar for all the respondents as it has been given either first or second priority, which reveals that highway geometrics disposal of water is not proper.

Table 4.26. Perception on Highway Improper Geometrics Disposal of Water

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	33.3	29.4	15.4	26.2
2	16.7	23.5	46.2	28.6
3	0.0	5.9	23.1	9.5
4	8.3	17.6	0.0	9.5
5	41.7	23.5	15.4	26.2
Total	100.0	100.0	100.0	100.0

4.4.6 Highway Maintenance Strategy Results Elaboration

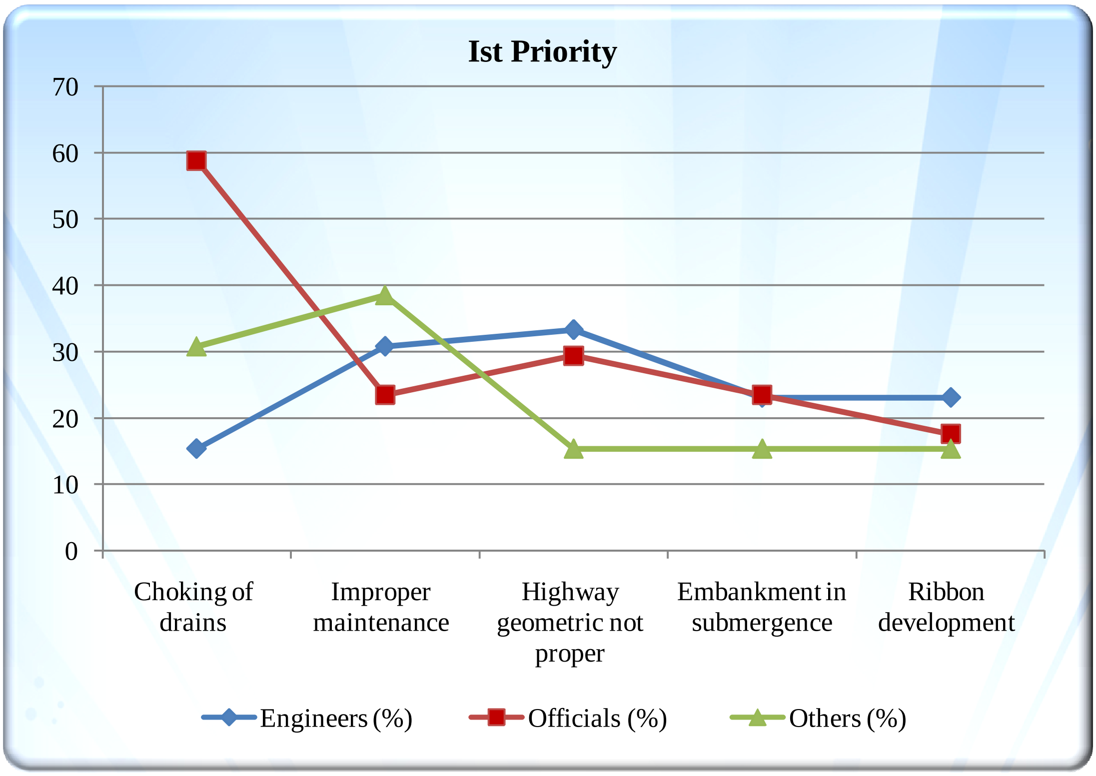
The concluding perceptions on maintenance are presented in Table 4.27, which represents the maintenance strategy according to top priority of opinions presented in Tables 4.34–4.26.

Table 4.27. Highway Maintenance Strategy: Priority-Wise Features

Features	Engineers		Officials		Others		All (%)
	Ist Priority (%)	Lower Priority (%)	Ist Priority (%)	Lower Priority (%)	Ist Priority (%)	Lower Priority (%)	
Choking of drains	15.4	46.2	58.8	17.6	30.8	23.1	31.98
Improper maintenance	30.8	30.8	23.5	23.5	38.5	46.2	32.21
Highway geometric not proper in disposal of water	33.3	41.7	29.4	23.5	15.4	46.2	31.58
Embankment in submergence	23.1	38.5	23.5	29.4	15.4	30.8	26.78
Ribbon development along the highway	23.1	30.8	17.6	29.4	15.4	38.5	25.8

Table 4.27 indicates that more than 30% of the engineers favour maintenance and highway geometrics, whereas highway officials prioritise the choking of the drains, which is their responsibility. The opinions on embankment submergence and ribbon development depict similar trends for all the respondents, that is, low priority.

Figure 4.4 displays maintenance strategy analysis of highways by using variables (Table 4.27) according to the perception survey data. The comparative variation of the maintenance strategy according to higher and lower priorities is represented in Figure 4.4.



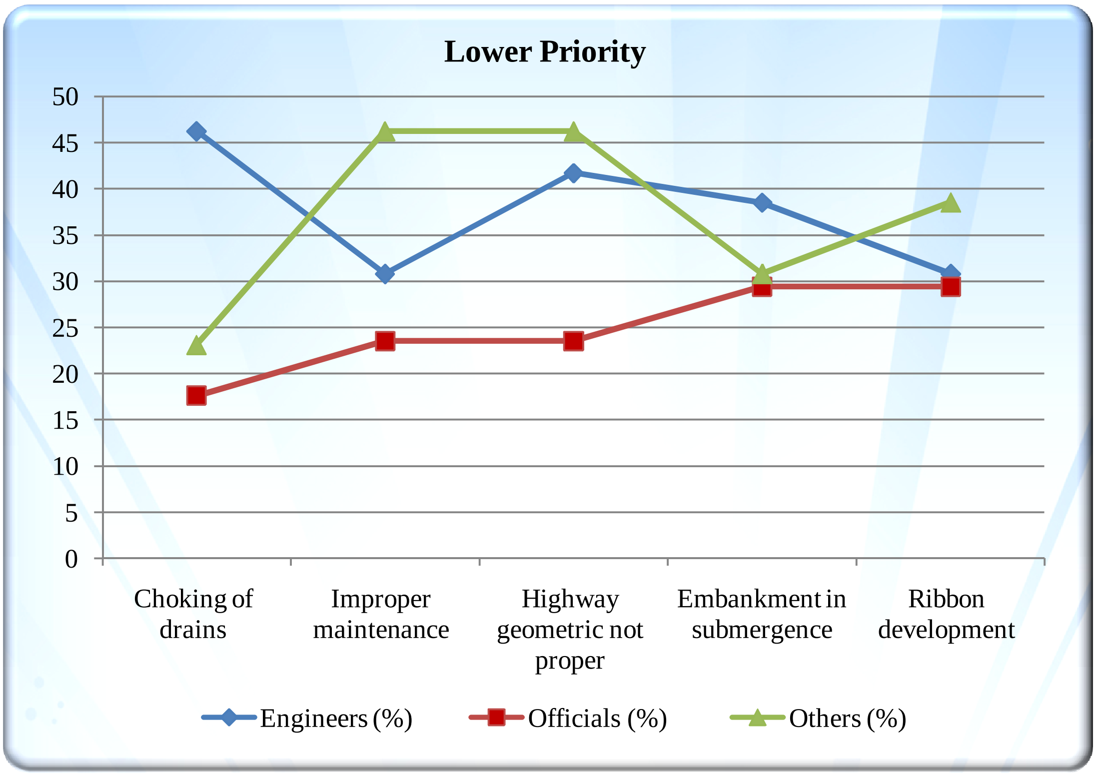


Figure 4.4. Perception Opinion Analysis of Maintenance Strategy on Highway

Highway engineers revealed the following considerations during opinion survey, which are essential in the maintenance strategy for smooth movement of traffic.

- The pavement maintenance agency must mandatorily provide route patrols round the clock to assist motorists. The patrol personnel should be adequately trained in traffic management, road safety, and primary first aid. The highway agency should also provide ambulances having all facilities of emergency assistance required such as a stretcher to carry the patient, emergency medicines, and oxygen.
- Service roads should to be constructed in habitant areas with road signs at all flaring locations.
- Pucca drain should be constructed in urban areas and service roads and covered to ensure pedestrian safety.

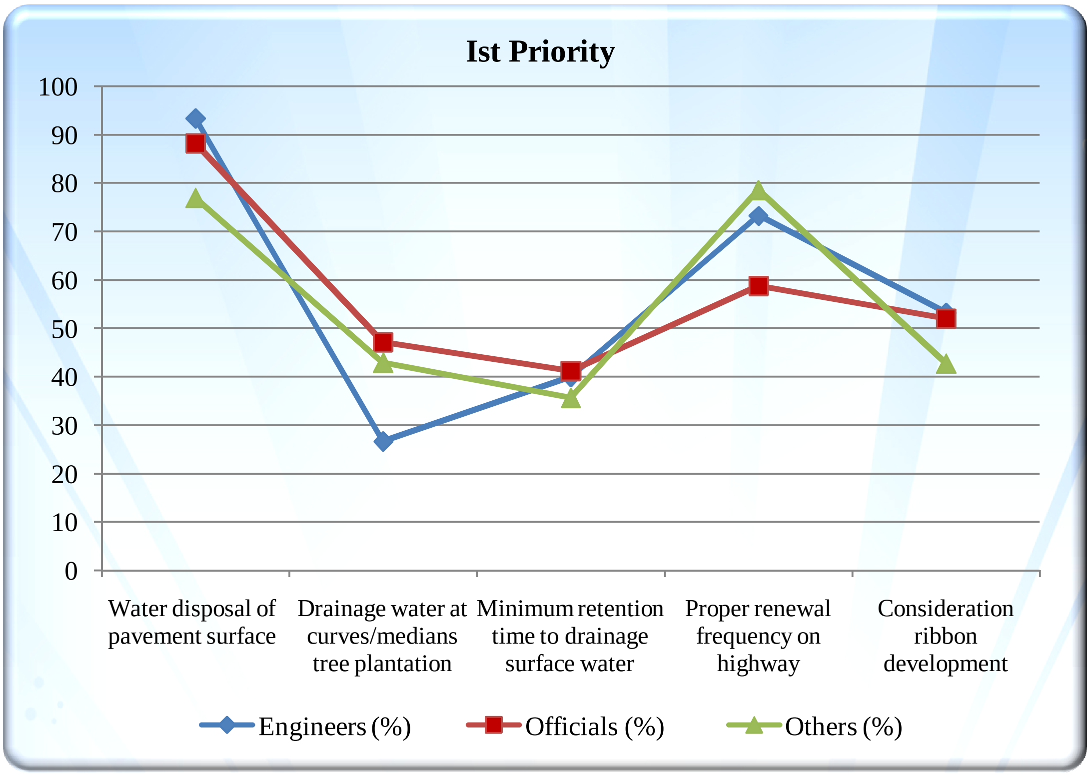
4.5 STAKE HOLDER OPINION TO IMPROVE PROBLEM ON EXISTING HIGHWAY DRAINAGE

Table 4.28 presents the results of perception survey conducted through a semi structured questionnaire; the three main perceptions supported by respondents are consideration of water disposal of pavement surface, followed by disposal of drainage water at curves and medians and minimum retention time to drain surface water. The other two perceptions to be incorporated in a highway design are frequency of maintenance and consideration of ribbon development. However, this opinion differs among all respondents with engineers prioritising water disposal of pavement and official sprioritising disposal of drainage water at curves and medians and using water for plantation. Respondents prioritised improvement of highway condition. Freedom was given to choose any other suggestion but hardly any suggestion was available.

Table 4.28. Stake Holder Opinion to Improve Highway Drainage

Suggestions	Engineers (%)		Officials (%)		Others (%)		All (%)
	Ist Priority	Lower Priority	Ist Priority	Lower Priority	Ist Priority	Lower Priority	
Consideration of water disposal at pavement surface for Routine Maintenance	93.4	6.7	88.2	11.8	77	13	48.35
Disposal of drainage water at curves and medians to be utilised for Tree plantation	26.7	46.7	47.1	47.1	42.9	35.7	41.03
Minimum retention time to drainage surface water	40	26.7	41.2	29.4	35.7	50	37.16
Proper renewal frequency on highway	73.3	26.7	58.8	35.3	78.6	21.4	49.01
Consideration ribbon development	53.3	33.3	52	47.1	42.8	57.8	47.71

Figure 4.5 derived using Table 4.28 presents the analysis of engineers, officials and other respondents with respect to perception proposed in the survey. The activities represented on horizontal axis are identified on the basis of field study in consultation with technical experts. The figure clearly indicates the analysis of perception to identify the importance of highway drainage features essential for improving the existing design. Engineers have given higher priority to water disposal of pavement surface, whereas highway officials prioritised disposal of drainage water at curves and medians and its use in tree plantation, which is economical in arid areas. Approximately 41% of engineer and officials gave first priority to minimum water retention time for draining pavement surface water and 50% other respondents gave it second priority. More than 50% of respondents also favoured the consideration of ribbon development on highways.



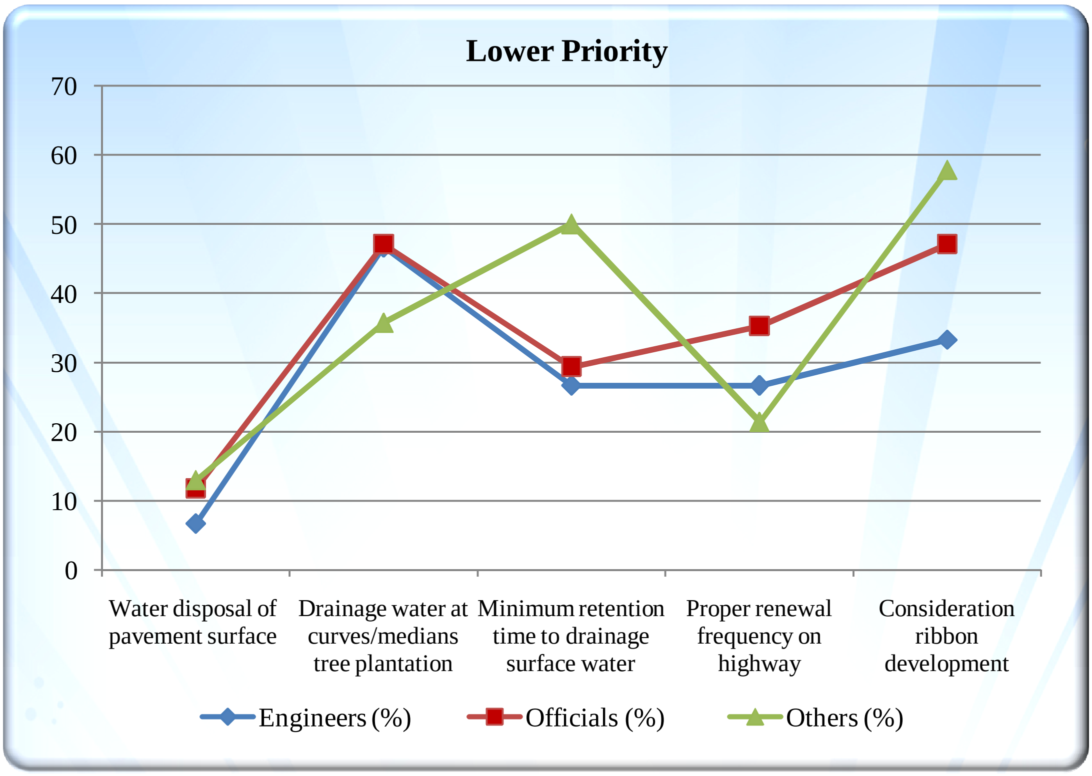


Figure 4.5. Line Diagram for Stake Holder Opinion for Improving Highway Drainage

The perception survey results depicted in Figures 4.1–4.5 are briefly summarised priority-wise as follows: the drainage and maintenance mechanism of transport design along with traffic management is essentially important for efficient highway roads transport system; stakeholders suggest consideration of water disposal at highway curve, regular maintenance, and consideration of ribbon development important in highway design system.

Photo 4 displays large area of pavement surface having no arrangement of quick disposal of surface water. The required drains are not available. The water retention time during the rainy days is more, which results in development of pot holes and patches. The photo represents poor drainage condition due to more water retention time on pavement surface NH-8.

Photo 4. Poor Drainage due to More Water Retention Time on NH-8

4.5.1 Minimum Retention Time for Drainage Water on Highway Surface

The major concerns of highway authorities is water logging on the road surface, which is the major cause of pot holes, patches, and road accidents (Table 4.29). Almost all the respondents suggested that the water should be drained from the surface within no time. This suggestion was given high priority equally by all the respondents. The minimum retention time can be reduced by providing harvesting wells on ROW at suitable distances according to drainage situations.

Table 4.29. Minimum Retention Time for Drainage Water on Highway Surface

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	40.0	41.2	35.7	39.1
2	26.7	29.4	50.0	34.8
3	20.0	29.4	14.3	21.7
4	13.3	0.0	0.0	4.3
5	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0

4.5.2 Utilisation of Drainage Water at Curves and Medians for Tree Plantation

As is well known, trees prevent floods during rains. The plantation developed with the help of pavement surface water at curves and medians can be designed for economical drainage (Table 4.30). Majority of the respondents recommend that the water disposed at the curves and medians should be used for planting trees. Tree plantation was supported by highway officials and others for further use of rain water by providing surface water storage tanks or harvesting tanks in ROW.

Table 4.30. Use of Drainage Water at Curves and Medians for Tree Plantation

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	26.7	47.1	42.9	39.1
2	46.7	47.1	35.7	43.5
3	26.7	5.9	21.4	17.4
Total	100.0	100.0	100.0	100.0

Highway engineers and officials revealed that median openings or drains for efficient drainage of surface water should be constructed in super elevated sections. Pucca Drain should be constructed in urban areas or service roads and covered to ensure safety of pedestrians and disposal of rain and household water.

4.5.3 Consideration Ribbon Development

Table 4.31 shows that approximately 50% of the respondents suggested considering ribbon development in highway planning and design. This was highly supported by engineers (53.3%) followed by high officials (54.0%) and others. The concept was highly supported by engineers, officials and other respondents in order for future ribbon development problem of highway drainage to be minimised by introducing harvesting well in ROW.

Table 4.31. Perception on Consideration Ribbon Development

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	53.3	52.0	42.8	50.0
2	33.3	47.1	57.1	45.7
3	13.3	0.0	0.0	4.3
4	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0

4.5.4 Frequency of Highway Maintenance

Table 4.32 shows that approximately 73.3% of engineers advised that the highway should be maintained frequently. Most of the engineers, officials, and others gave high priority to the frequency of maintenance. A highway that is maintained frequently reduces the possibility of occurrence of accidents to some extent.

Table 4.32. Frequency of Highway Maintenance

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	73.3	58.8	78.6	69.6
2	26.7	35.3	21.4	28.3
3	0.0	0.0	0.0	0.0
4	0.0	5.9	0.0	2.2
Total	100.0	100.0	100.0	100.0

4.5.5 Routine Maintenance

Approximately 87% of the respondents suggested that roads should be maintained monthly represented (Table 4.33). Proper maintenance would keep the roads free from patches, cracks, and water logging. The water collection on pavement surface develops patches or potholes, which are the major hurdle in the smooth flow of traffic and cause accidents. Hence, properly maintained highways reduce accidents by improving safety.

Table 4.33. Routine Maintenance

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	93.4	88.2	78.6	87.0
2	6.7	11.8	21.4	13.0
3	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0

Some of the good, bad, and problematic factors of the present highway design have been highlighted earlier in this thesis. The suggestions for improvement include the consideration for water disposal at highway curves, higher frequency of maintenance, and consideration for ribbon development. However, the views differ among the officials and engineers, who, on the basis of their experiences, have given suggestions such as high frequency of maintenance and disposal of water at curves and medians. Other respondents emphasised more on the retention time of surface drainage.

Improper drainage with pot holes, stagnant water on the surface and design and construction defects are important factors for poor maintenance of highways. Lastly, three important factors for the improving highway designs are highway drainage, reconsideration for future ribbon developments, genuine maintenance and safety consideration to minimise accidents.

4.6 ALTERNATE DESIGN PERCEPTION FOR PRESENT SYSTEM

As per the survey conducted using semi structured questionnaire, suggestions for improvement of present highway design system are briefly analysed as follows.

Table 4.34 presents the priorities of perception on suggestions for improving present highway road designs. The safety consideration to minimise accidents is given the top priority, followed by consideration of ribbon development, requirement of genuine maintenance, utilisation of highway drainage water, and water disposal at highway curves. The engineers give very high priority to safety consideration to minimise accidents, and the remainder of the factors are in similar order of preference. However, highway officials and other officials give first and second priority the safety consideration. In Table 4.3.4, the third and fourth important factors are genuine maintenance and miscellaneous use of highway drainage water.

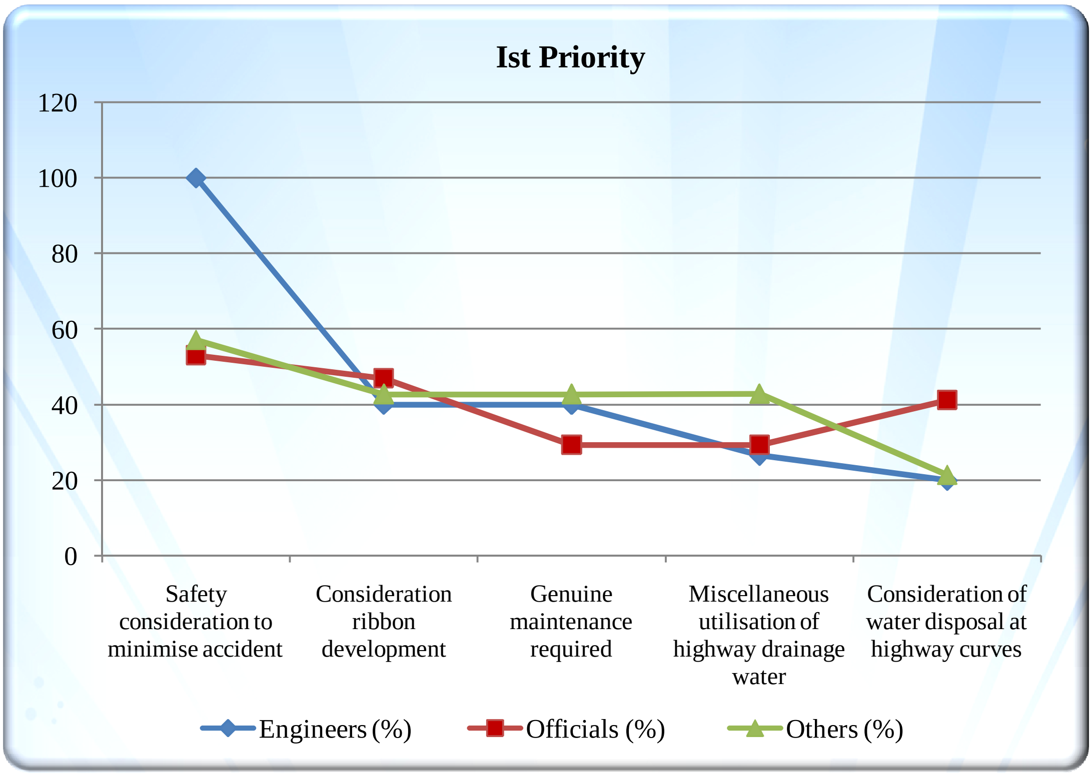
Hence, in future alternate highway designs, consideration of safety and ribbon development and genuine maintenance must be given top priority. The respondents have given significant lower priorities to miscellaneous use of water including its disposal at curves.

Table 4.34. Alternate Design Suggestions on the Basis of Priority

Suggestions	Engineers (%)		Officials (%)		Others (%)		All (%)
	Ist Priority	Lower Priority	Ist Priority	Lower Priority	Ist Priority	Lower Priority	
Safety consideration to minimise accident	100	0	53	29.4	57.1	21.4	43.48
Consideration ribbon development	40	33.3	47	23.8	42.8	35.7	37.1
Genuine maintenance required	40	33.3	29.4	41.4	42.8	28.6	35.91
Miscellaneous utilisation of highway drainage water	26.6	46.7	29.4	35.3	42.9	35.7	36.1
Consideration of water disposal at highway curves	20	46.7	41.2	41.2	21.4	35.7	34.3

Figure 4.6 is derived using Table 4.34, and illustrates the comparative analysis of suggestive perception factors for highway drainage, which include genuine maintenance, safety consideration and importance of miscellaneous use of water.

In addition, engineers have also given significant lower priorities to miscellaneous use of water collected from highway drainage system indicating specific problems when disposing surface water at curves.



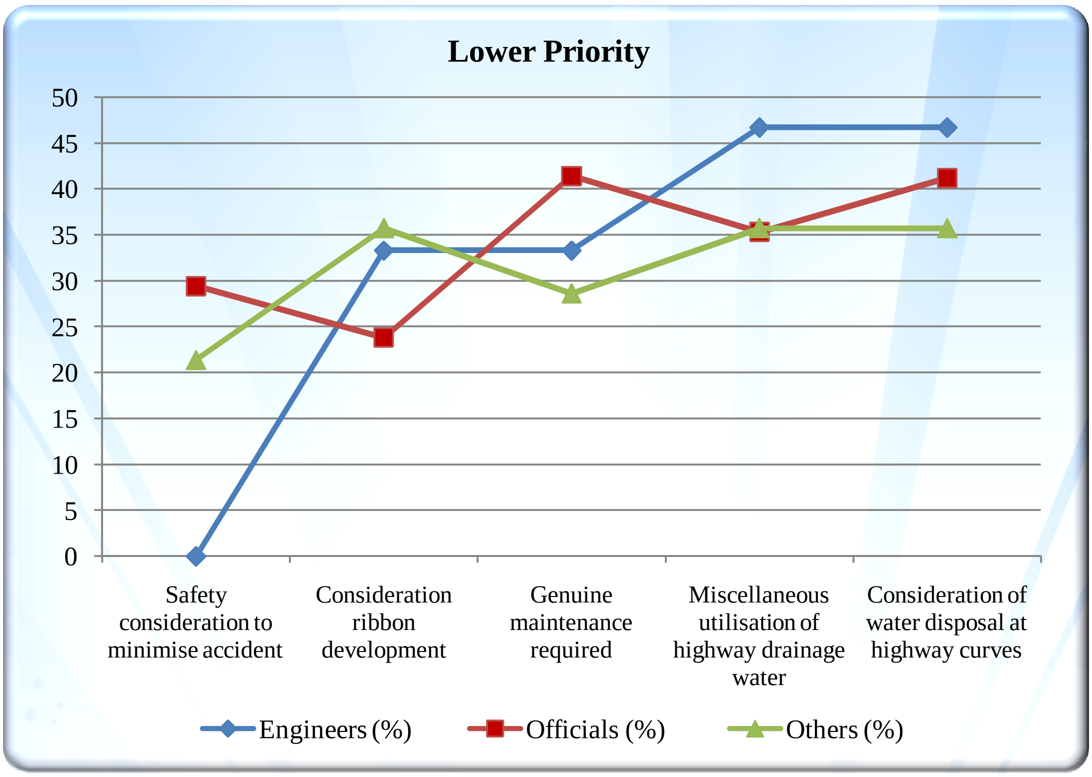


Figure 4.6. Comparative Analysis Prioritising Suggestive Factors of Highway Drainage, Maintenance and Safety

During the perception survey, highway officials also suggested that the need for proper designing to improve road safety (Safety Engineering) must be given top priority. This includes regular road safety audits and removal of bottlenecks; providing traffic education to school children, which is a lifelong benefit to society, publicity programmes and spreading of road-safety awareness; need of driver training and testing; financing road safety programmes; and proper enforcement of traffic laws are focused upon as special remarks in the questionnaire.

In addition, respondents reported the safety standards of highway vehicle users, which include seat belts, headrests, air bags, special seats for children, periodic inspections combined with frequent random checking of vehicles, emergency medical services, timely and proper treatment, and encouraging road safety.

Furthermore, highway officials have revealed that government alone is not responsible for road safety; civil society and other organisations such as commercial sectors, service organisations, and nongovernmental organisations (NGOs) also play an important role in spreading road safety awareness. At grass-roots level, NGOs can provide an important input. Allotment of maintenance cost with a proper implementation plan for proper traffic management and providing safety awareness to road users is essential. The Government of India must make efforts to minimise the increase in accidents. RSA is extremely essential for the existing and proposed new highways. The establishment of NRSC, State Road Safety Council, and District Committees under MORTH of states and UTs is necessary.

4.6.1 Opinion for Ribbon Development

Table 4.35 presents the detailed perceptions, which also have priorities similar to those of Table 4.34.

Approximately 43.5% of the respondents gave weightage to the reconsideration of ribbon development. The responses of all respondents show that highway officials have given higher weightage to the consideration of ribbon development compared to other respondents.

Table 4.35. Perception of Ribbon Development

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	40.0	47.0	42.8	43.5
2	13.3	23.5	7.1	15.2
3	13.3	11.8	35.7	19.6
4	33.3	17.6	14.3	21.7
Total	100.0	100.0	100.0	100.0

4. 6.2 Opinion on Water Disposal at Curves

Table 4.36 shows that water disposal at highway curves is not highly preferred. More than 41% of the respondents showed their consideration for water disposal at highway curves and highway officials have given low weightage to this factor.

Highway officials further revealed that median opening or drains should be constructed in super elevated sections for efficient drainage of surface water.

Table 4.36. Perception of Water Disposal at Highway Curves

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	20.0	41.2	21.4	28.3
2	13.3	11.8	28.6	17.4
3	20.0	5.9	14.3	13.0
4	46.7	41.2	35.7	41.3
Total	100.0	100.0	100.0	100.0

Furthermore, as a special remark, highway engineers and other workers revealed about the poor design and lack of maintenance. For the safety of highway roads, horizontal and vertical curves should be designed for proper drainage,which should be checked regularly to ensure adequate super elevation. Moreover, transition lengths should be provided at curves with enough sight distance and adequate vertical clearances must be provided under all the flyovers and vehicular underpasses for proper disposal of road surface water.

4.6.3 Opinion for Miscellaneous Use of Highway Drainage Water

Table 4.37 shows that more than 32% of the respondents emphasised on the use of drainage water. Approximately 43% of other respondents prioritised the miscellaneous use of water. Approximately 40% of respondents gave this factor second priority.

Table 4.37. Perception for Miscellaneous use of Highway Drainage Water

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	26.6	29.4	42.9	32.6
2	46.7	35.3	35.7	39.1
3	26.7	17.6	21.4	21.7
4	0.0	17.6	0.0	6.5
Total	100.0	100.0	100.0	100.0

4.6.4 Opinion for Safety Consideration to Minimise Accident

Photo represents the situation of an NH-8 junction, where no traffic management, traffic signal, or channelization of traffic is observed. The traffic policemen seems helpless to control the traffic near the junction. In such situations, grade separator is essential for smooth and safe movement of traffic.

Photo 5. Describing Poor Traffic Management Enhance Accident on NH-8

Approximately 70.0% of the respondents highly considered road safety for minimising accidents (Table 4.38). This was highly favoured by all the engineers, followed by more than half of the officials, and others. The maintenance of roads is not sufficient to minimise accidents; other factors such as speed, condition of vehicles, road design, environmental factors, and human errors are also responsible to a large extent, as revealed in the perception study.

The informal observations in the questionnaire, reveal the design and maintenance problems on highway roads. The following points are highlighted for the safety on highway projects, in additional suggestions and remarks, by respondents (Table 4.38).

Table 4.38. Perception for Safety Consideration to Minimise Accident

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	100.0	53.0	57.1	69.6
2	0.0	17.6	7.1	8.7
3	0.0	29.4	14.3	15.2
4	0.0	0.0	21.4	6.5
Total	100.0	100.0	100.0	100.0

- Crash barriers should be provided on embankments, whose height is more than 3.0m, at major and minor bridge approaches and sharp curves.
- Installation of road studs is essential in all junctions.
- Speed limit and informatory sign boards must be installed at merging and diverging lanes, major junctions, and petrol pumps. All signs should be reflector type with high intensity retro-reflective sheeting.
- Adequate lighting arrangement on all major and minor junctions of the highway should be installed with high mast lighting arrangement for safe movement of vehicular traffic and safety of pedestrians.
- Raised foot path must be provided in towns and villages for safety of pedestrians.
- Informatory sign boards must be installed in front of bus bays and lorry lay-bys.
- Proper designing of highway roads to improve road safety (Safety Engineering).
- Regular RSAs and removal of bottlenecks as per traffic requirements.
- Financing road safety programmes through vehicle registration.
- Encouraging road safety research.

4.6.5 Opinions for Genuine Maintenance

Table 4.39 shows more than 37% of the respondents suggested genuine maintenance roads. Among all the respondents, only 40% were engineers followed by others. More than 41% officials have given second priority for genuine maintenance.

Table 4.39. Perceptions on Genuine Maintenance Required

Priority Rank	Engineers (%)	Officials (%)	Others (%)	All (%)
1	40.0	29.4	42.8	37.0
2	26.7	5.9	21.4	17.4
3	33.3	41.2	7.1	28.3
4	0.0	23.5	28.6	17.4
Total	100.0	100.0	100.0	100.0

In the survey, officials also suggested the following:

- Increase of the maintenance cost with a proper implementation plan.
- Following highway maintenance schedule.
- The area of study gets irregular rains; therefore, they moderately affect the area (but cannot be generalised).

4.7 PERCEPTION OF HIGHWAY VEHICLE DRIVERS

During the perception survey, some engineers also elicited some of the challenges they might face in the future. The growing use of telecommunication and other technology (e.g., route guidance, infotainment, and cell phones in vehicles) distracts drivers. However, very few of them know enough about how this equipment is used and how it affects driver attention. There are hardly any laws prohibiting the use of this technology when driving. Is there any other solution required? (e.g., blocking of cell phone transmissions when vehicle is in motion). There is a growing problem of such technological use, and how prepared we are and what steps needs to be taken for road safety are interesting areas for future research. The survey was also conducted to analyse the problem of safety and maintenance through perception of drivers and highway users.

4.7.1 Perception on Monthly Expenditure of Vehicle

According to Table 4.40, the average monthly expenditure of lorry and bus is significantly higher than other vehicles. Heavy vehicles such as buses and trucks are mostly used for freight and passenger transfer from one place to another and are affected with more wear and tear.

Table 4.40. Perception on Monthly Expenditure by Vehicle

Vehicle type	Monthly Expenditure (in Rs.) approx.
Car	2600
Jeep	4100
Motor Cycle	1250
Lorry/Bus	14875
Three wheelers	4397

Therefore, according to their size and distance coverage, expenditure incurred for maintenance is higher compared to other vehicles.

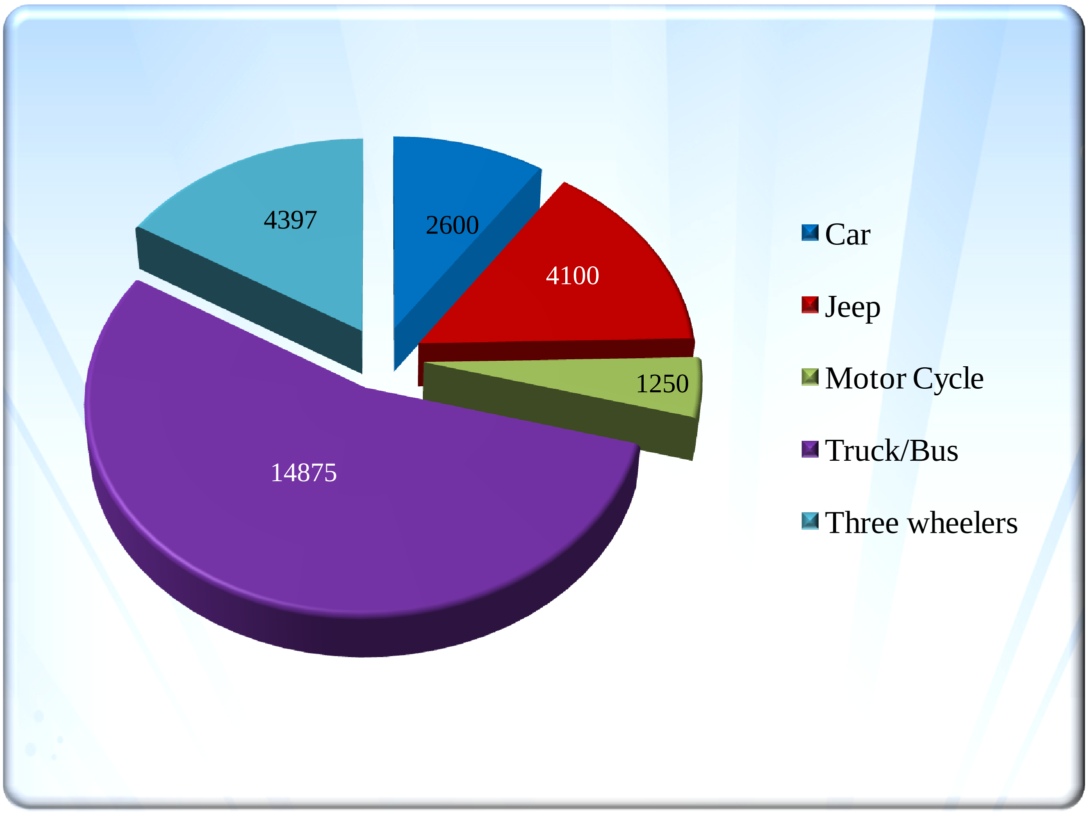


Figure 4.7. Comparison of Vehicle Maintenance Cost (In Rupees) with Vehicle Type

Figure 4.7 is derived using Table 4.40; it provides a comparison of monthly expenditure with respect to vehicle type.

4.7.2 Perception on Causes of Increase in Maintenance and Operation Cost of Vehicle

Most of the respondents that is 87.9% revealed that vehicle maintenance cost can be reduced by improving road condition presented in Table 4.41. According to the survey, condition of road, driver’s driving habits and life of vehicles, old or news are the three main factor responsible for higher vehicle maintenance cost on highways.

Table 4.41. Factors Affecting Vehicle Maintenance Cost on Highway

Factors	Number	Reasons (%)
Condition of Road	255	87.9
Driver's Habits	240	82.8
Life of Vehicle New or Old	170	58.6
Maintenance of Vehicle itself	125	43.1
Cost of Vehicle	80	27.6
Total	290	100

As seen in Table 4.41, 82.8% respondents agreed that drivers' habits affect safety. Hence, VOC can be minimised by improving condition of roads, which is an indicator of maintenance.

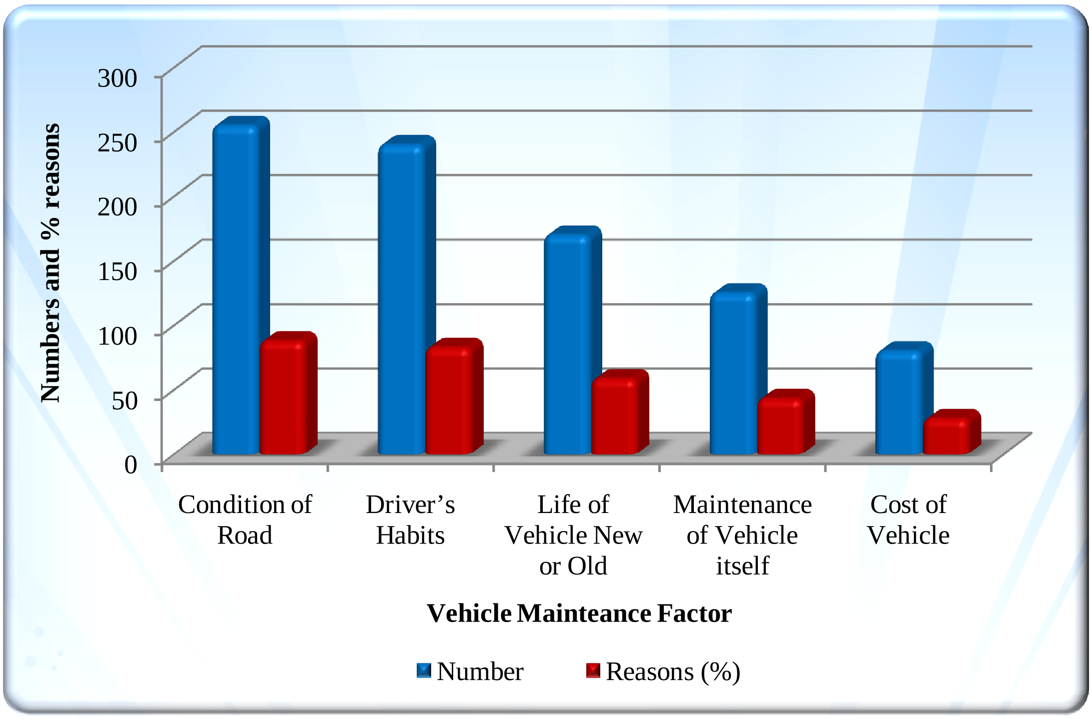


Figure 4.8. Analysis of General Factors of Accident Relating Vehicular Operation

Figure 4.8 is derived using Table 4.41, and shows the analysis of number of respondents and their opinions given for the five factors. The figure clearly indicates that the condition of road is the most important factor for vehicle maintenance on highways. Proper highway drainage and maintenance of road may improve the condition of roads. Hence, proper highway drainage and maintenance are good features for highway design system. In addition, drivers' habits must also be considered as safety factors.

4.7.3 Perception Factors of Highway Geometrics and Maintenance on Vehicle Operation

Maintenance of highways, drainage system, and surface conditions of highways are other three factors that affect the maintenance cost of vehicle on highways (Table 4.42). Few others perceive that highway curve design and accident free zones are factors affecting maintenance of vehicle on highways. Hence, maintenance of highway with proper drainage is important for reducing VOC.

Table 4.42. Perception Factors on Maintenance of Vehicle on Highway

Highway Activity Factors	Number	Reasons (%)
Maintenance of Highway	275	91.7
Drainage System	230	76.7
Riding Surface	160	53.3
Highway Curve	145	48.3
Accident Free highway	75	25.0
Total	300	100

The analysis of number of accidents, percentage of reasons of five features including maintenance of highway, drainage system, riding surface highway, curves and accident free highway are represented in Figure 4.9.

The Figure clearly indicates that more than half of the respondents agree that proper drainage of highway and maintenance will result in good riding surface.

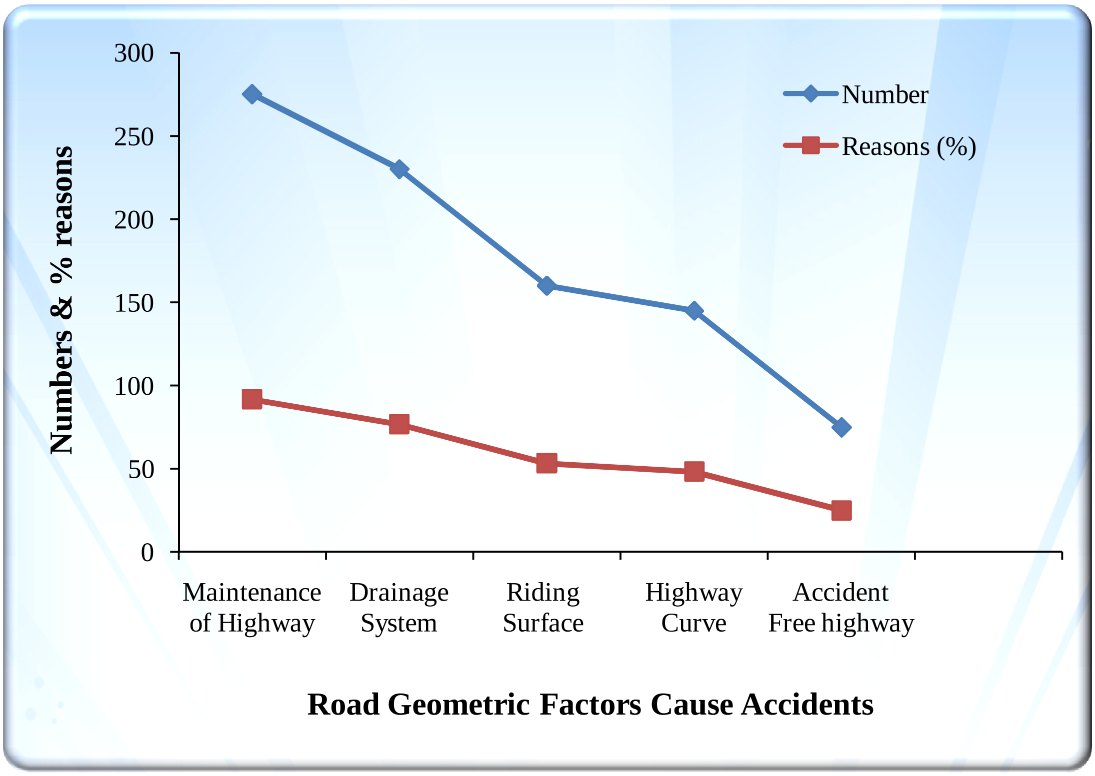


Figure 4.9. Analysis of Highway Geometric Factor with Accidents

4.7.4 Perception on Accidents Reasons of Highways

Table 4.43 presents the reasons of accidents on highways according to the respondents of the survey: lack of traffic management and untimely increase maintenance of highways. Improper drainage systems with presence of patches on surfaces, recklessness on the part of drivers and improper vehicle maintenance also result in accidents. Hence, traffic management and maintenance of road are important for minimising road accidents.

The factors that cause accidents and deaths such as human errors: neglect in driving or irrational driver behaviour; and infrastructure problems: inadequate roads, road width, width and state of shoulders, and width of the median. Furthermore, the distance travelled, number of trips in transportation, road environment, number of motorised vehicles, and motorised traffic, are associated with the country's development and income levels of its people.

Table 4.43. Perception on Accidents Reasons of Highways

Highway Activity Factors	Number	Reasons
Lack of Traffic management	200	66.7
Untimely maintenance of highway	155	51.7
Absence of drainage on surface or patches	100	33.3
Carelessness of driver	105	35.0
Insufficient maintenance of vehicle	90	30.0
Total	300	100

Figure 4.10 is derived using Table 4.43 and represents the analysis of general factors of safety on highway for understanding the result of perception survey on the lack of traffic management, untimely maintenance of highway, absence of drainage on surface or patches, carelessness of drivers, and insufficient maintenance of vehicles.

Figure 4.10 clearly indicates that approximately half of the respondents reveal that lack of traffic management, poor maintenance, and absence of drainage or patches are responsible for accidents.

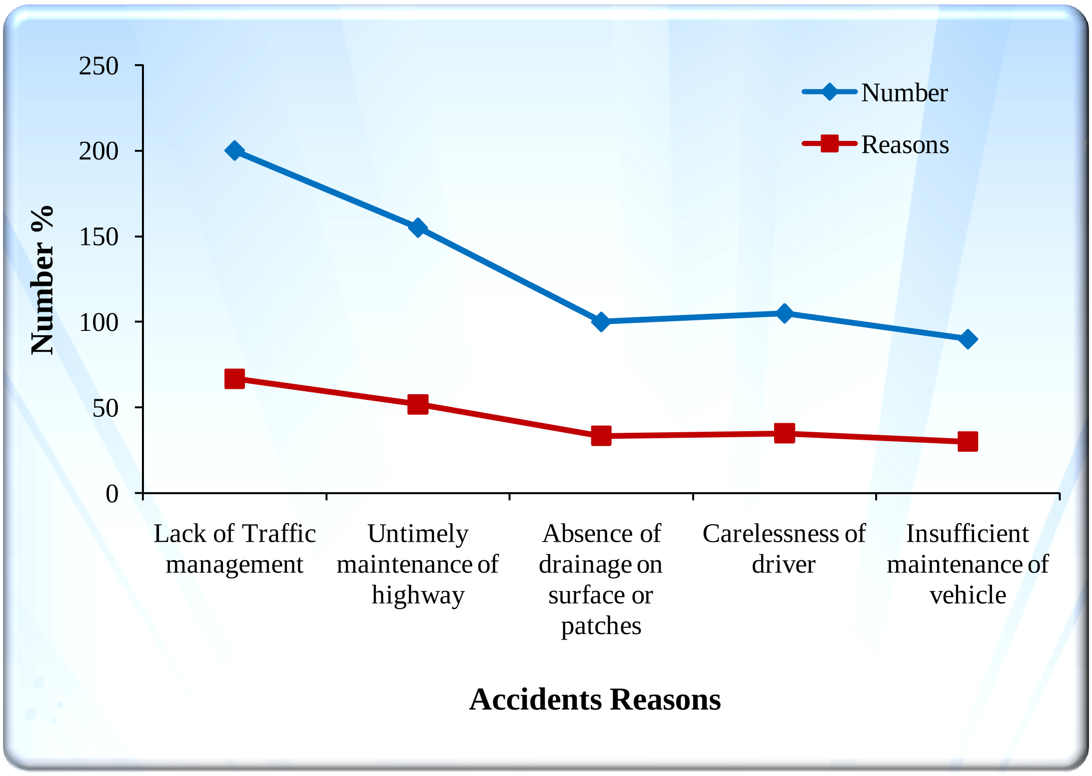


Figure 4.10. Analysed Reasons of Accident on Highway

4.7.5 Perception of Measures to Tackle Accident

Measures to tackle accidents also include vehicle and highway maintenance, as discussed in Table 4.44. The timely maintenance of highways, proper drainage system, sign board, lights on highways, and proper traffic management are the necessary measures for tackling accidents on highways. Hence, improving the safety on highways, genuine maintenance and proper drainage are essential factors for future improvement of highway designs.

Table 4.44: Measure to Tackle Accidents

Measures	Number	%
Timely maintenance of highway	255	85.0
Proper water drainage system	260	86.7
Lane marking / Sign Board	250	83.3
Management of Lights on the highway	235	78.3
Proper Traffic management	235	78.3
Total	300	100.0

Additional suggestions revealed by highway drivers and users are as follows:

- Providing traffic education to children in schools, which is lifelong benefit to society regarding road safety.
- Publicity programmes and spreading of awareness about road safety.
- Driver training and testing.
- Proper enforcement of traffic laws.
- Vehicle safety standards, such as seat belts, headrests, air bags, special seats for children, protection of the occupants with periodic inspections and frequent random checking of vehicles.
- Emergency medical services for reduction of severity of injury of crash victims in road casualties, timely, and proper treatment.

Figure 4.11 is derived using Table 4.44 and presents analysis of measures to reduce accidents by perception data on timely maintenance of highway, proper water drainage system, lane marking, sign boards, management of lights on the highway, and proper traffic management. More than 75% of respondents favour timely maintenance, proper drainage, and traffic management in highway design systems.

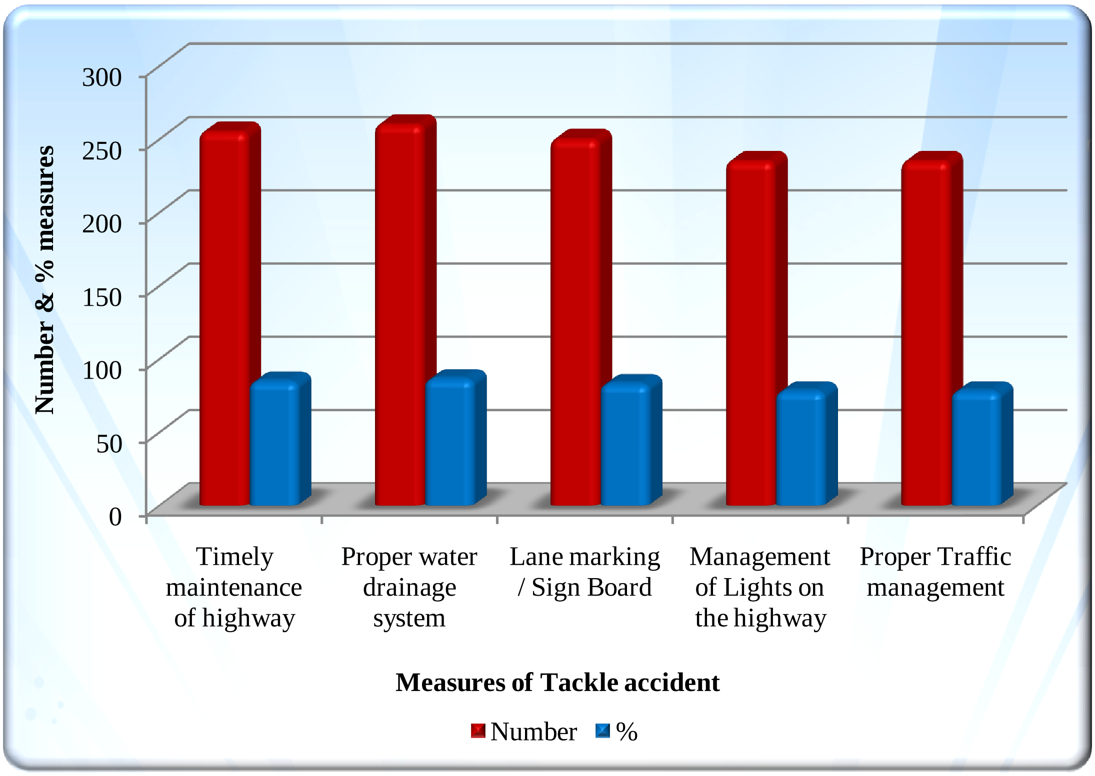


Figure 4.11. Analysis of Highway Features to Reduce Accidents

Proper water drainage system, sign board, proper lighting, genuine maintenance and proper traffic management are necessary factors to tackle the accident problem.

Highway road users revealed through the questionnaire that lack of traffic management, improper maintenance of highway, and absence of drainage, apart from individual factors such as carelessness in driving and insufficient maintenance of vehicle are responsible for higher number of accidents. Hence, accident data study analysis is also essential for highway safety.

4.7.6 Perception on Direct and Indirect Impact of Accident

Finally, the perceptions on both direct impact and indirect impact of accidents on highway roads are presented in Table 4.45. According to the respondents, the main outcome of direct impact is loss of human life. The other direct impacts are vehicle damage and huge expenditure incurred on medical care. Furthermore, indirect impacts include future damages due to injury and death of people in hospital, traffic congestion on highways, and future medical expenditure.

Table 4.45. Direct and Indirect Impact of Accidents

Reasons	%
Direct Impact	
Vehicle Damage	75.9
Loss of life	92.3
Expenditure on medical	35.8
Indirect Impact	
Highway jam or delay	51.0
Medical expenditure	53.8
In Injury/Death future damage	92.7

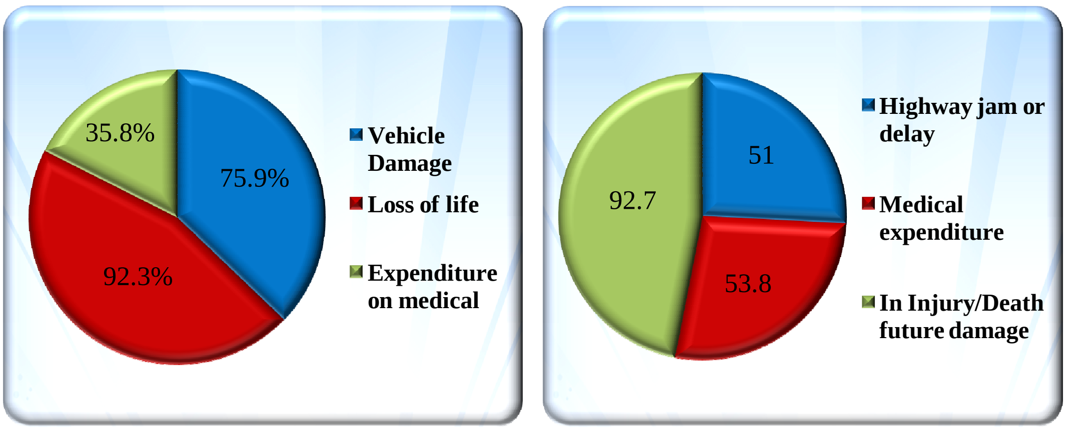


Figure 4.12. Pie-Chart of Reasons
(Percentage of Direct and Indirect Impacts of Accidents)

Figure 4.12 is derived using perception data in Table 4.45 on direct and indirect impact of accidents, to understand objectives of safety on highways. The main outcome for direct loss are loss of life and vehicle damage. The indirect losses are due to highway congestion or delay, medical expenditure, and injury or future deaths.

As highway drivers and other road users did not reveal much on accidents and safety, further accident data analysis was conducted, for which results and discussion are mentioned in the successive sections regarding identification of important factors of safety.

4.8 HIGHWAY SAFETY BY ACCIDENT ANALYSIS OF INDIAN ROADS

Data in Table 4.46 were obtained using secondary data of MORTH (Road accident 2012). The number of fatal road accidents increased from 71,000 in 2001 to 1,23,000 in 2012, and number of people killed increased from 81,000 to 1,38,000 during the same period. Some improvement was observed in recent years as a result of concerted and coordinated road safety efforts. The number of road accidents, deaths and injuries declined in 2012 compared to 2011. Since 2000, the total number of road accidents registered a decline for two consecutive years (i.e., 2011 and 2012) (Table 4.46; Figure 4.13). In contrast the proportion of fatal accidents from the total road accidents has consistently increased since 2003 from 18.1% to 25.1% in 2012. The severity of road accidents, measured in terms of deaths per 100 accidents increased from 20 in 2001 to 27 in 2012. However, this number declined to 27.1 during 2012 from to 27.9 in 2011. According to the resultant consequences, further road safety efforts for the highway design system are represented in the successive subsections.

Figure 4.13 is derived using accident details in India during 2001–2012 in terms of the number of accidents (in thousands), deaths, injuries(in thousands), and accident severity.

Table 4.46. Accidents Detail, India, 2001–2012

Year	No of Accidents (Thousand)		No of Persons (Thousand)		Accident severity*
	Total	Fatal	Death	Injured	
2001	405.6	71.2	80.9	405.2	20.0
2002	407.5	73.6	84.7	408.7	20.7
2003	406.7	73.6	85.9	435.1	19.7
2004	429.9	79.4	92.6	465.5	19.9
2005	439.3	83.5	95.1	465.3	20.4
2006	460.9	93.9	105.7	496.5	21.3
2007	479.2	101.2	114.4	513.3	22.3
2008	484.7	106.6	119.9	523.2	22.9
2009	486.4	110.9	125.7	515.5	24.4
2010	499.6	119.6	134.5	527.5	25.5
2011	497.7	121.6	142.5	511.4	27.9
2012	490.4	123.1	138.3	509.7	27.1

***Death out of those injured**

Because of safety efforts, the dip in the line diagram after the year 2010 is clearly indicates reduction in accidents.

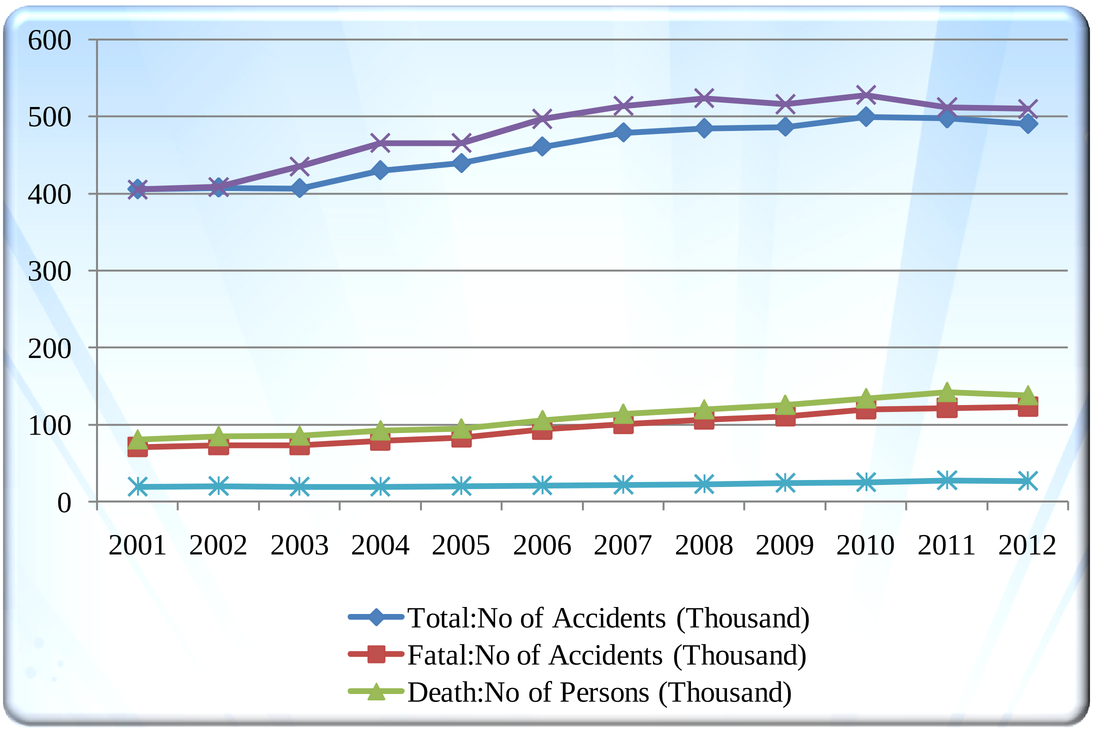


Figure 4.13. Graphical Representation of Accident Details in India 2001–2012

Figure 4.14 illustrates the increase in traffic fatalities and serious injuries occurring in India from 1992 to 2012. It shows that the compound annual growth rate of accidents and injuries during the last two decades has reduced but rate of death has increased more than eight fold (Road safety policy, 2012). This indicates that the severity of injuries has increased because of high traffic speeds, congestions, and poor traffic management.

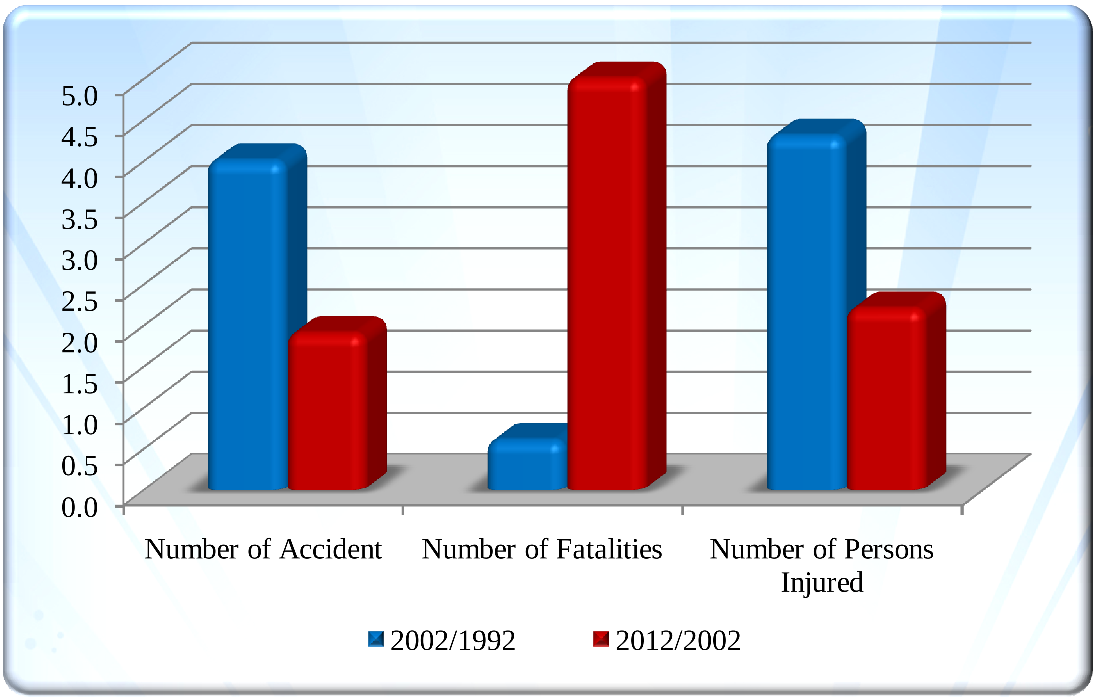


Figure 4.14. Compound Growth Rate of Accidents, Death and Injuries During the Decade

Figure 4.15 depicts the road accidents on normalisation per lakh of population and ten thousands of vehicles. It shows that the rate of accident per lakh population has continuously reduced over the years but the rate of accident per ten thousands of vehicles has increased during that period (Road accident 2012). Furthermore, to obtain an appropriate count of the incidences of accidents and deaths, normalised and standardised rates have been worked out in terms of number of accidents per lakh of people, accidents per ten thousands of motor vehicles, and road deaths per lakh of population.

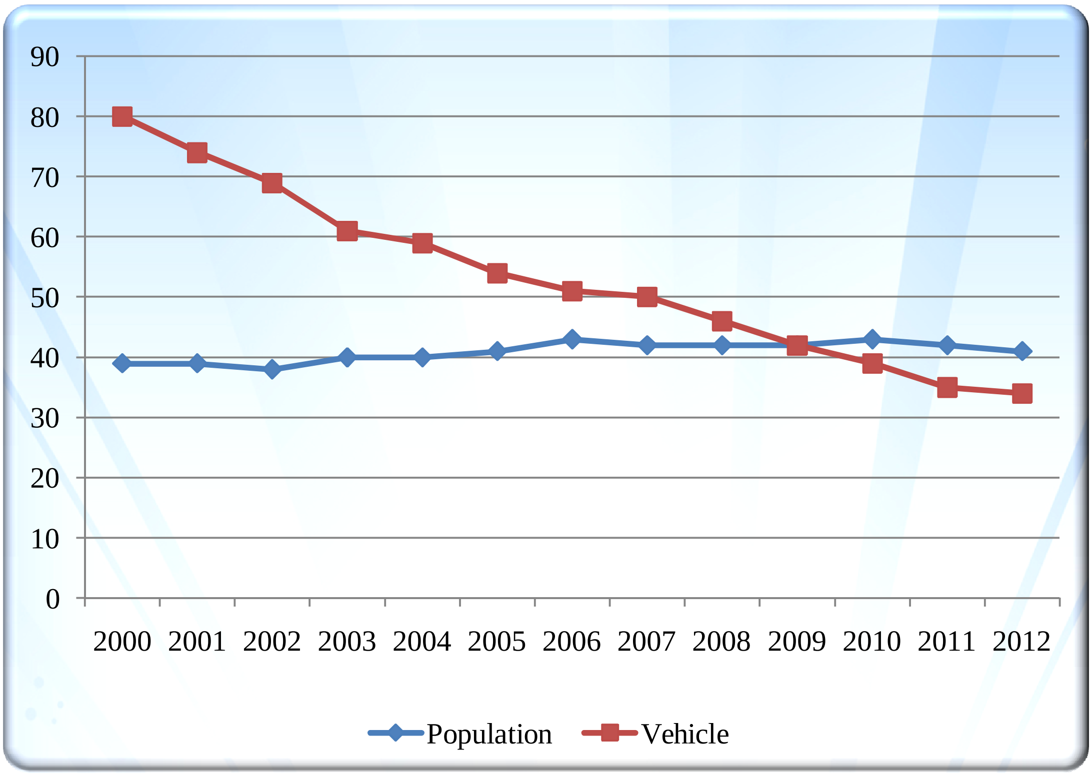


Figure 4.15. Year-Wise Road Accidents on per Lakh Population and Ten Thousands of Vehicles

Number of accidents per lakh population has continuously declined over the years and reduced more than half during the last decade from 80 accidents per lakh population in 2000 to 34 accidents per lakh population in 2012. Contrary to accident per lakh population, accidents per ten thousand vehicles have marginally increased from 39 in 2000 to 41 in 2012. Analysis of accident data shows that although the intensity of growth has come down drastically, improper management of vehicles is the major cause of accidents (WHO, 2012).

Figure 4.16 depicts fluctuation in the number of people injured per lakh of population; 39 in 2000 to 46 in 2008. This number declined to 42 in 2012. This indicates that road injuries increased for most of the years in the last decade; however, after 2008, a declining trend is seen on Indian roads.

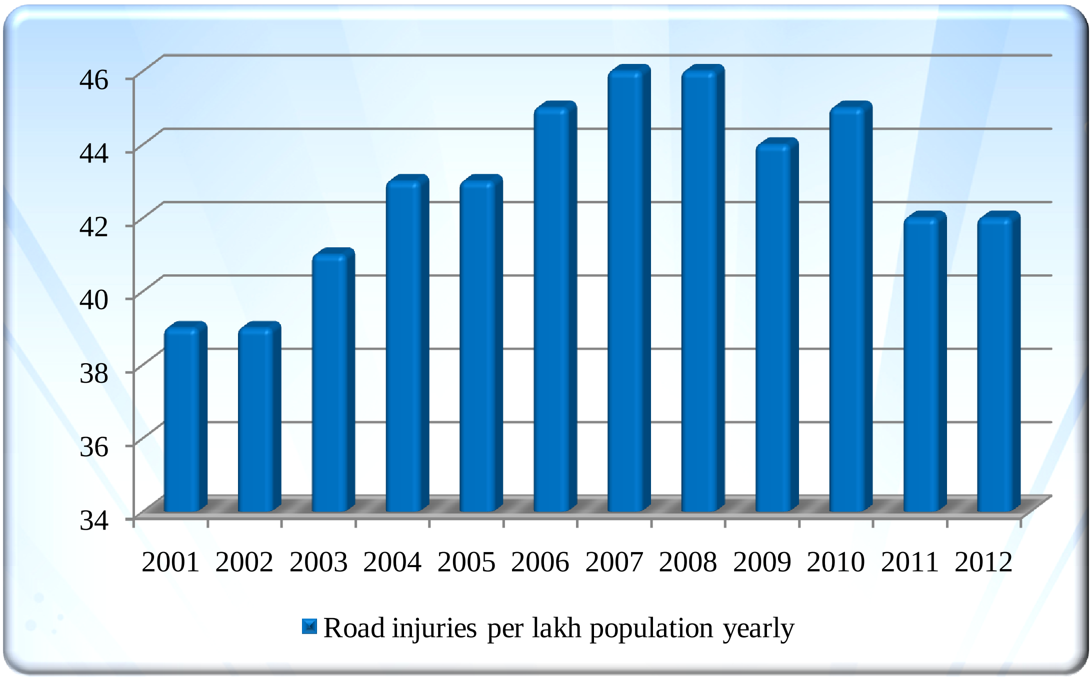


Figure 4.16. Road Injuries per lakh Population Yearly

Figure 4.17 illustrates the number of deaths per lakh of population, which increased from 8 in 2000 to 12 in 2011 and marginally declined during the same period from 12 to 11. This highlights the road safety efforts made, which proves hypothesis of road safety importance in a highway design system.

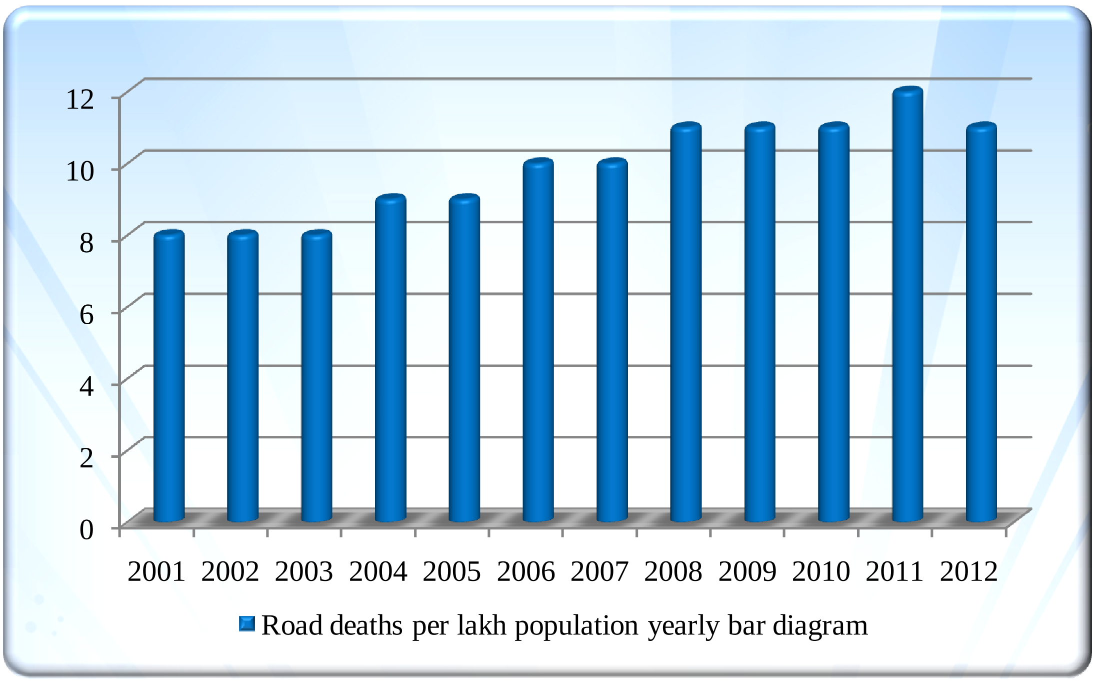


Figure 4.17. Road Deaths per Lakh Population Yearly

Figure 4.18 presents the major classification of Indian roads as NH, SH and ODR. NHs account for less than one-third of (29%) total road accidents and injured (30%) but more than one-third (35%) of deaths due to road accidents during 2012. SHs account for quarter of (24%) of total accidents and injured (26%) with similar share (27%) in the total number of deaths during 2012. Contrastively, more accidents and injured with lower percentage of deaths were reported for the other roads. This indicates the problem of highways design system, which permits greater speed resulting in relatively greater number of road accidents and fatalities. The reduction in road death per lakh population in Figure 4.17 during year 2011–12 is the result of road safety efforts in India. The death and casualties on Indian highways are more because of poor traffic management and limited length and width for catering 40% of the country's traffic (NHAI 2012; Road accident 2012).

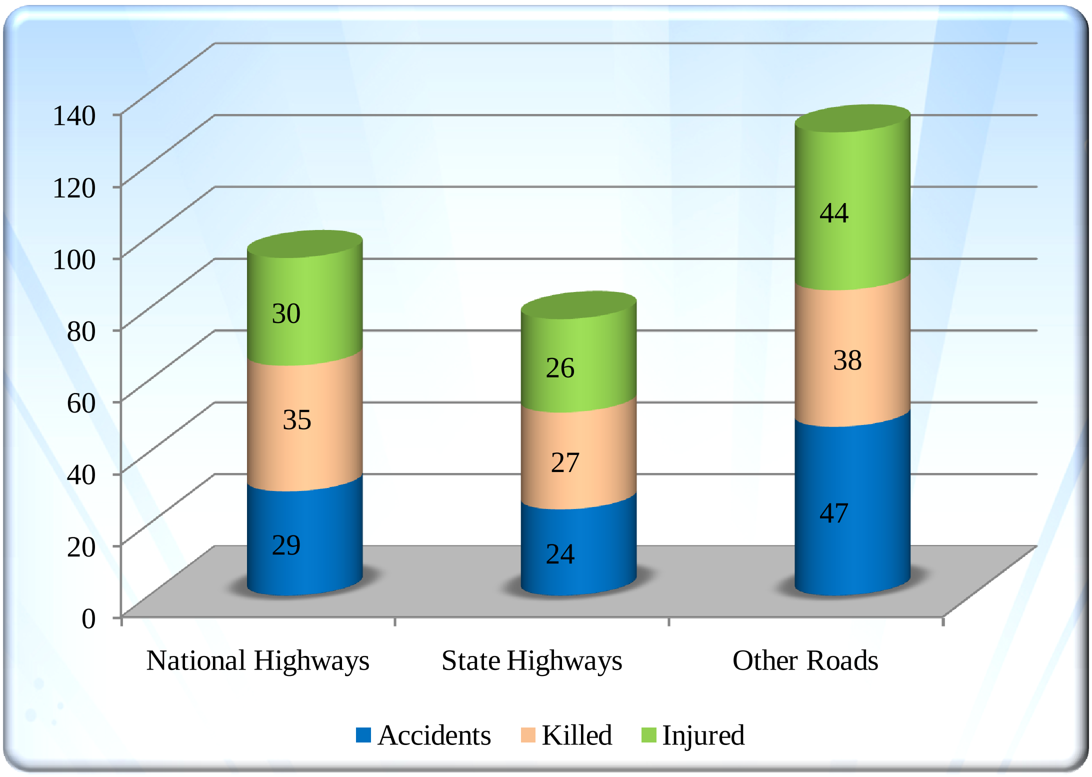


Figure 4.18. Comparison of Accidents, Deaths and Injuries as Per Road Category

Other factors such as defects in road, defects in vehicle, pedestrians' fault, cyclists' fault, and weather conditions also play some role in road accidents rates. The accident analysis highlights the lack of footpaths, service lanes, cycle tracks, and traffic measures for reducing speed, which have increased the risk of accidents and its severity.

4.8.1 State-Wise Road Accident and Death

Figures 4.19–4.21 present state-wise break up of accidents, fatalities, and severity of road accidents on Indian roads. It provides information about the share of top five states in India in the total number of road accidents and deaths, and top ten states having highest severity of road accidents. The share of top five states in the total number of road accidents in the country has increased in 2012 compared to 2011. The top five states in order of highest to lowest share of road accidents are Maharashtra, Tamil Nadu, Madhya Pradesh, Andhra Pradesh, and Karnataka (Road accident 2012).

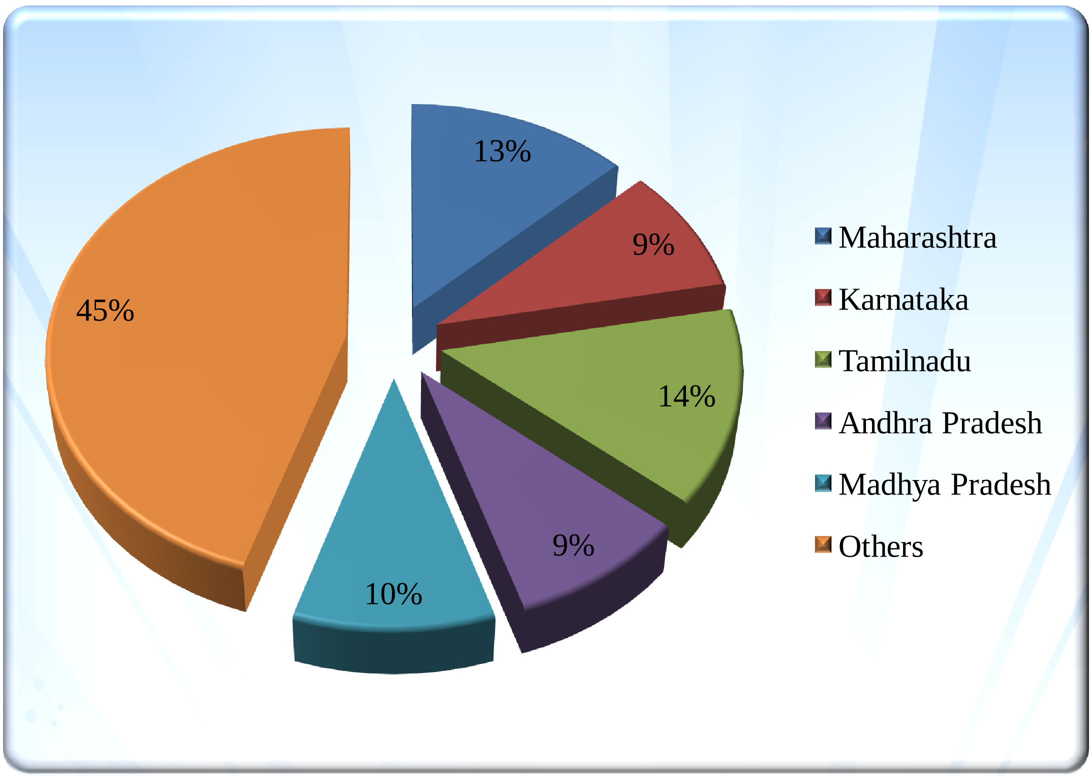


Figure 4.19. Top Five State on Share of Total Percentage of Accidents

The share of the top 5 states in the total number deaths in road accidents in the country also declined to 51% during 2012 compared to 52% in 2011. Among the top five states, which lead in the share of deaths in road accidents, in order of highest to lowest, are Uttar Pradesh, Tamil Nadu, Madhya Pradesh, Maharashtra, and Rajasthan. Rajasthan and Uttar Pradesh did not constitute the top five in the list of accidents but ranked at the top in accident-related deaths.

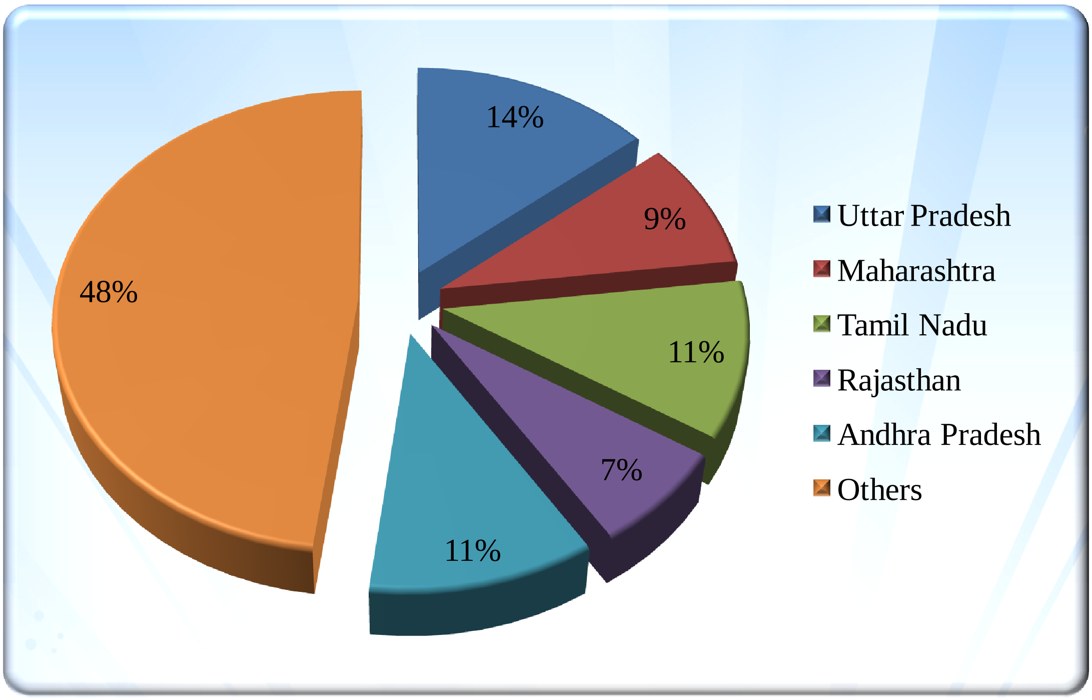


Figure 4.20. Top Five State on Percentage Share of Total People Died in Road Accidents

Maharashtra, Tamil Nadu and Andhra Pradesh are the top three state that contribute in the total share of accidents and deaths.

However, the state comparisons of accidents have limitations, and must be viewed keeping in mind the differences in road network, state of roads, number of humans and vehicles, levels of urbanisation, and accident reporting systems. These parameters play a significant role in accident rates. The severity of road accidents is presented in Figure 4.21 on basis of the aforementioned parameters.

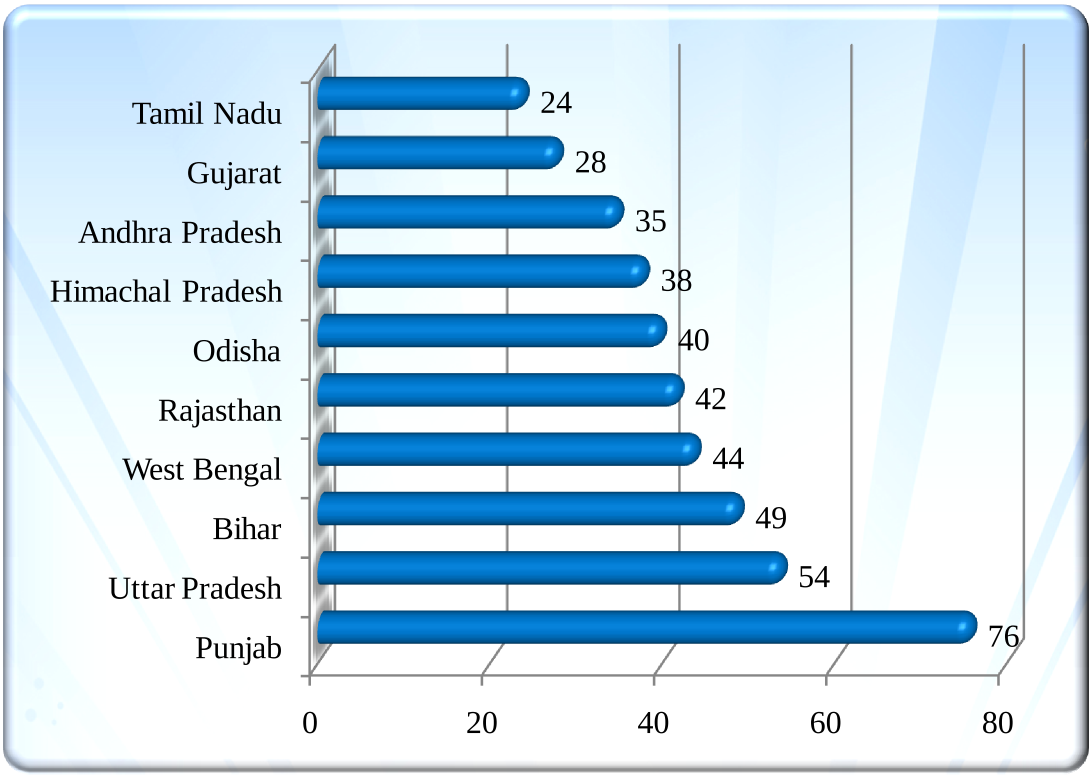


Figure 4.21: State-wise Severity of Road Accidents (Deaths Per 100 Accidents)

In the severity of road accident, most of the underdeveloped states ranked in the top ten, except Punjab and Gujarat. These two states cater to a large number of heavy vehicles with more highway traffic movements than others, which attributed to the high severity in road accidents.

4.8.2 Cause of Road Accidents

The major cause of accidents in developing countries is not necessarily negligence during driving or irrational driver behaviour; on careful study, one could understand that the infrastructure provided for the road users are not adequate enough to cater to the needs. On the basis of widespread scientific research involving analysis of road accidents and studies on how vehicles are driven under different road conditions, several possible road design indicators that contribute to accidents are as follows:

Insufficient road width, state of shoulders, width of median, poor grades of highway road, deficiency in site distance, radius of horizontal curves including deficiency in super elevation at curve, inadequate or improper provision of road user information and guidance facilities, lack of protective measures for errant or run-off-the-road vehicles, absence of traffic segregation particularly at rural–urban interface, lack of assessment of control measures, poor safety management during construction, and absence of gore area treatment at approaches to grade separated structure.

However, road accidents leading to deaths and injuries largely dependent on the distance travelled, defined as the number of trips in transportation, time in the road environment, number of motorised vehicles, and motorised traffic. However, these factors are mainly associated with the country's development and income level of its people. In developed countries, risk of road accidents due to these factors has been reduced through effective road safety engineering, traffic management, enforcement of traffic laws, and severity of penalties for infringement (Shanker et al. 1995). Figure 4.22 illustrate that in India, three-fourth of the road accidents occurred because of the drivers. Other factors such as defect in road (2%), defect in vehicle (2%), pedestrians' fault (3%), cyclists' fault (1%), and weather conditions (1%) also play some role in road accidents. (Hallmark et al. 2002; Seeck et al. 2009).

This phenomenon of Indian road accidents in modern road systems designed for the motor vehicles exposing vulnerable road users to greater risk of accidents. In developing countries such as India, lack of footpaths, service lanes, cycle tracks, and measures to reduce speed where non–motorised mode of transport blend with motorised traffic increases the risk of accidents and its severity. These factors have contributed towards increase in road related accidents, injuries, and deaths in relation to increasing road length. Highway safety can be enhanced by providing facilities for pedestrians and cyclists along with speed reduction schemes, thereby weakening the nexus between road accidents, injuries, and deaths with development of road network (WHO 2012).

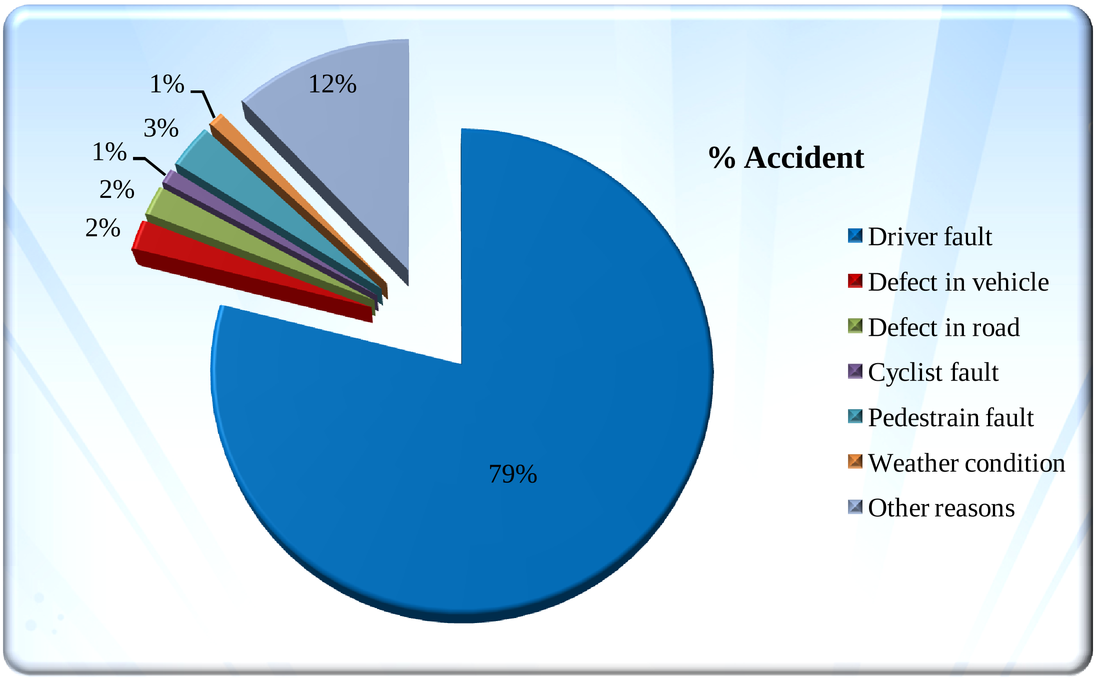


Figure 4.22. Analysis of Causes of Road Accidents in India

4.9 IMPORTANT FACTORS AND RELATIONSHIP OF FIND SURVEY DATA BETWEEN GOOD AND BAD FEATURES

The analysation of interdependence/relationship between good and bad features of highway design systems are represented as follows:

Table 4.47 presents a correlation matrix that has been prepared to examine the association between the variables. In addition, important factors are identified by using factor analysis. Kendall's correlation is a nonparametric measure of association for ordinal or ranked variables. The sign of the coefficient indicates the direction of the relationship, and its absolute value indicates the strength, with larger absolute values indicating stronger relationships. Possible values range from −1 to 1, but a value of −1 or +1 is analysed from square tables.

Table 4.47. Correlations Results of Good Features of Present Highway with Maintenance

Good /bad features variables	Proper drainage of water	Good riding surface	Highway crust no failure	Proper traffic management	Regular maintenance and safety	Improper drainage	Improper surface camber	Irregular renewal	Design defects
Proper drainage of water	1.000	0.184	0.093	**.332(*)**	0.076	0.181	-.216	**-.347(*)**	0.025
Good riding surface	0.184	1.000	0.015	0.120	**0.316(*)**	-.072	.112	-.114	-.029
Highway crust no failure	0.093	0.015	1.000	**0.385(**)**	**.433(**)**	0.060	**-.361(**)**	**-.304(*)**	-.044
Proper traffic management	**0.332(*)**	-.120	**.385(**)**	1.000	0.020	0.048	-.090	-.103	0.075
Regular maintenance and safety	0.076	**.316(*)**	**-.433(**)**	0.020	1.000	0.130	-.152	-.232	-.148
Improper drainage	0.181	-.072	0.060	0.048	0.130	1.000	0.126	**.347(**)**	0.053
Improper surface camber	-.216	0.112	**-.361(**)**	-.090	-.152	0.126	1.000	**0.319(*)**	**0.297 (*)**
Irregular renewal	**-.347(*)**	-.114	**-.304(*)**	-.103	-.232	**.347(**)**	**.319(*)**	1.000	**.254(*)**
Design defects	0.025	-.029	-.044	0.075	-.148	0.053	**0.297(*)**	**0.254(*)**	1.000

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

** Correlation is significant at the 0.01 level (2-tailed).Number:40 (Observations)

The correlation matrix presented in the Table 4.47 shows significant meaningful results that are briefly given by using the Kendall coefficient.

(i) A proper drainage system has moderate significant relationship with proper traffic management and irregular renewal with correlation coefficients of +0.332 and 0.347, respectively.

(ii) A good riding surface is only moderately related to regular maintenance and safety having coefficient of +0.316.

(iii) Highway crust no sign of failure is an important variable with a highly significant relationship with proper traffic management, regular maintenance and safety, and improper surface camber and is moderately related to irregular renewal representing correlation coefficients of +0.385, +0.433, –0.361, and –0.347, respectively.

(iv) Proper traffic management is significantly related to proper drainage of water and no failure of highway crust with correlation coefficient of +0.332.

(v) Regular maintenance and safety factor is significantly related to no failure of highway crust and good riding surface with correlation coefficients of + 0.385, + 0.433, –0.316, respectively.

(vi) Improper drainage is significantly associated with irregular renewal, poor traffic management, highway in submergence and improper maintenance schedule with correlation coefficients of +0.347, +0.352, +0.361, +0.285, respectively.

(vii) Improper surface camber is associated with irregular renewal and design defect with correlation coefficients of−0.319 and +0.297, respectively.

(viii) Irregular renewal is associated with improper maintenance schedule, improper drainage at curve, improper surface drainage and improper surface camber with design defect with correlation coefficients if +0.312, +0.290, +0.347, −0.319, and−0.254, respectively.

(ix) Design defect is associated with improper highway safety, proper traffic management, improper surface camber, and irregular renewal with correlation coefficients of +0.299, +0.310, +0.297, −254, respectively.

Hence, good features of highway design are proper drainage of water, proper traffic management, regular highway maintenance, and safety with no sign of highway crust failure.

Finally, improper surface camber, irregular renewal and design deficit are significant good features of present highway roads. Along with good riding surface and proper drainage system of water, three other important variables for good feature or highway design are proper traffic management on highway road, highway safety schedule, and highway in submergence variables.

Hence, drainage is moderately correlated with maintenance and traffic safety of highway, which is the hypothesis of this research.

The correlation presented in Table 4.48 shows significant and meaningful results represented using the Kendall coefficient.

(i) Highway in submergence shows significant relationship with improper drainage, poor traffic management, and improper maintenance with Kendall coefficients of +0.361, −0.401, and −0.320, respectively.

Table 4.48. Correlations Results of Bad Feature of Present Highway with Maintenance

Bad features variables	Highway in submergence	Improper maintenance schedule	Improper Highway safety	Improper drainage of high curves	Poor traffic management	Improper drainage	Improper surface camber	Irregular renewal	Design defects
Highway in submergence	1.000	**-.320(*)**	0.149	0.037	**-.401(**)**	**0.361(**)**	0.112	-.122	-.035
Improper maintenance schedule	**-.320(*)**	1.000	**-.359(**)**	**0.409(**)**	0.172	**0.285(*)**	0.158	**0.312(*)**	-.118
Improper Highway safety	0.149	**-.359(**)**	1.000	0.081	**0.347(**)**	0.164	-.078	-.225	0.**299(*)**
Improper drainage of highway curves	0.037	**0.409(**)**	0.081	1.000	**0.339(**)**	0.241	0.080	**0.290(*)**	0.154
Poor traffic management	**0.401(**)**	0.172	**0 .347(**)**	**0.339(**)**	1.000	**0.352(**)**	0.078	**0.266(*)**	**0.310(*)**
Improper drainage	**0.361(**)**	**0.285(*)**	0.164	0.241	**0.352(**)**	1.000	-.126	**0.347(**)**	0.053
Improper surface camber	0.112	0.158	-.078	0.080	0.078	-.126	1.000	**-.319(*)**	**0.297(*)**
Irregular renewal	-.122	**0.312(*)**	-.225	**0.290(*)**	**0.266(*)**	**0.347(**)**	**-.319(*)**	1.000	**-.254(*)**
Design defects	-.035	-.118	**0.299(*)**	00.154	**0.310(*)**	0.053	**0.297(*)**	**-.254(*)**	1.000

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

** Correlation is significant at the 0.01 level (2-tailed). Number: 40 (Observations).

(ii) Highway in submergence is significantly related to improper drainage, poor traffic management, improper maintenance with Kendall coefficients of +0.361, −0.401, and −0.320, respectively.

(iii) Improper maintenance schedule is significantly related to improper drainage and irregular renewal with correlation coefficient of + 0.409 and+ 0.312, respectively.

(iv) Improper highway safety is significantly related to poor traffic management and design effect with improper maintenance with correlation coefficients +0.347, +0.299, and−0.357, respectively.

(v) Improper drainage of high curve is significantly related to irregular renewal, improper maintenance and poor traffic management with correlation coefficients of +0.290, + 0.409, and +0.339, respectively.

(vi) Poor traffic management is significantly related to highway in submergence, improper safety, improper drainage at curve, improper drainage system, and irregular renewal with correlation coefficients +0.401, +0.339, +0.352, +0.347, and +0.266, respectively.

This indicates that poor traffic management, improper drainage, irregular renewal, design defects highway in submergence, improper maintenance schedule, highway safety, and improper drainage of highway curves are related with each other as is proved using Kendall coefficients.

4.10 PERCEPTION DATA FACTOR ANALYSIS RESULTS

The survey data collected using a semi structured questionnaire was analysed using a principal factor method to obtain various factors and their Eigen values for meaningful results. Tables 4.49–4.56 represent the results obtained to understand the research objectives. In the following sections, important factors of good and bad feature of present highway design, poor conditions of maintenance, and improvement of present highway design have been identified using the factor analysis technique. The factors must have an Eigen value greater than zero to be retained and identified by their factor loading as positive.

4.10.1 Good Features of Present Highway Design System

The results obtained using the principal factor method are represented in Tables 4.49–4.50 as follows: a1: Proper drainage of water, a2: Good Riding surface, a3: proper traffic management, a4: Highway crust no sign failure, a5: Regular maintenance schedule. These are derived using additional perception results recorded in Tables 4.1–4.5.

Number of observations	=	40	Method: Principal factors
Retained factors	=	4	Rotation: (unrotated)
Number of params	=	10	

Table 4.49. Result of Factor Analysis on Good Feature of Present Highway System

Factor	Eigen value	Difference	Proportion	Cumulative
Factor 1	1.73236	0.69310	0.5299	0.5299
Factor 2	1.03926	0.57373	0.3179	0.8478
Factor 3	0.46552	0.18819	0.1424	0.9902
Factor 4	0.27734	0.52251	0.0848	1.0750
Factor 5	-0.24517		-0.0750	1.0000

LR test: independent vs. saturated: $chi^2(10)$ = 74.26 Prob>chi^2 = 0.0000

The good feature of present highway road has five components. The factor analysis method shows that the first component explains 53% of the variation in the data. Earlier perception results data represented in Tables 4.1–4.5 are further analyse during the principal factor method presented in Table 4.50.

Table 4.50. Factor Loadings (Pattern Matrix) and Unique Variances

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Uniqueness
a1	0.3781	0.6154	0.1742	-0.2982	0.3590
a2	0.4148	-0.5547	0.4215	0.0922	0.3341
a3	0.6971	-0.0198	-0.4606	0.1380	0.2825
a4	-0.7298	-0.3972	-0.1913	-0.2450	0.2130
a5	-0.6315	0.4412	0.0939	0.3175	0.2969

Furthermore, the factor loading of the first factor showed that proper traffic management, good riding surface, and proper drainage system of water are three most important variables for a highway design system, in which optimum maintenance is possible.

4.10.2 Bad Features of Present Highway System

The results obtained using the principal factor method has been represented in Tables 4.51–4.52 as follows: b1: Highway in submergence; b2: maintenance schedule is improper; b3: Highway safety schedule is not proper; b4: highway of high median and curves is not proper; b5: Poor traffic management on drainage; these are derived by perception in Tables 4.7–4.11.

Number of observations	=	43	Method: principal factors
Retained factors	=	4	Rotation: (unrotated)
Number of params	=	10	

Table 4.51. Factor Analysis of Bad Feature of Present Highway System

Factor	Eigen value	Difference	Proportion	Cumulative
Factor 1	1.80097	1.33306	0.7178	0.7178
Factor 2	0.46790	0.13163	0.1865	0.9043
Factor 3	0.33627	0.11113	0.1340	1.0383
Factor 4	0.22514	0.54632	0.0897	1.1280
Factor 5	-0.32118		-0.1280	1.0000

LR test: independent vs. saturated: $chi^2(10)$ = 61.05 Prob>chi^2 = 0.0000

The first components explain 72% variation in the data. Results of factor loading of first factor further explain poor traffic management on highways. The perception data recorded in Tables 4.7–4.11 were further analysed using the principal factor method, and the results are reproduced in Table 4.52.

Table 4.52. Factor Loadings (Pattern Matrix) and Unique Variances

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Uniqueness
b1	0.4581	0.0422	0.3799	0.2595	0.5766
b2	-0.7324	0.2275	-0.2318	0.2026	0.3171
b3	0.5552	0.4131	-0.0514	-0.2484	0.4567
b4	0.5716	-0.4261	-0.2775	0.0291	0.4139
b5	-0.6479	-0.2493	0.2419	-0.2327	0.4054

Factor loading of factors 1 and 2 show that improper highway safety schedule and highway in submergence variables are most important bad features of a highway design system for highway drainage in context of safety and maintenance.

4.10.3 Poor Condition of Maintenance

The survey data and results obtained by principal factor analysis are represented in Tables 4.53–4.54 by the denotations: c1-Drainage is not proper, enhance to develop pot holes/Patches; c2-Surface camber allows stagnant water on pavement; c3-Regular Renewal is not being applied; c4-Design and construction defects appearance on highway surface. These perceptions are recorded in Tables 4.12–4.15.

Number of Observations = 46 Method: principal factors

Retained Factors = 3 Rotation: (unrotated)

Number of Params = 6

Table 4.53. Factor Analysis of Poor Condition of Maintenance

Factor	Eigen value	Difference	Proportion	Cumulative
Factor 1	**1.25445**	**0.27503**	**0.5555**	**0.5555**
Factor 2	0.97943	0.68565	0.4337	0.9892
Factor 3	0.29378	0.56315	0.1301	1.1193
Factor 4	-0.26937		-0.1193	1.0000

LR test: independent vs. saturated: chi^2 (6) = 58.19 Prob>chi^2 = 0.0000

The first component explains 56% of the variation in the data. The perception data mentioned in Tables 4.12–4.15 were further analysed using the principal factor method, and the results are recorded in Table 4.54.

Table 4.54. Factor Loadings (Pattern Matrix) and Unique Variances

Variable	Factor 1	Factor 2	Factor 3	Uniqueness
C1	0.6109	0.1323	0.3833	0.4624
C2	0.3183	-0.7070	-0.2121	0.3538
C3	-0.8654	-0.0283	0.1335	0.2325
C4	0.1763	0.6792	-0.2899	0.4236

Furthermore, factor loading of the first factor of the variables shows that improper drainage with pot holes, stagnant water on surface, and design and construction defects are the important factors for poor maintenance of highway roads, which are cause by improper drainage of water on pavement surface.

4.10.4 Suggestion for Improvement of Present Highway Design System

The respondents perceptions were analysed using the principal factor method that is represented using Tables 4.55 and 4.56 as D1: consideration of ribbon development; D2: consideration of water disposal at highway curves; D3: miscellaneous use of highway drainage water; D4: safety consideration to minimise accidents; D5: genuine maintenance required. These perceptions are recorded in Tables 4.35–4.39.

Number of observations	=	46	Method: principal factors
Retained factors	=	4	Rotation: (unrotated)
Number of params	=	10	

Table 4.55. Suggestion for Improvement of Present Highway Design System

Factor	Eigen value	Difference	Proportion	Cumulative
Factor 1	1.03701	0.08562	0.4922	0.4922
Factor 2	0.95139	0.60798	0.4515	0.9437
Factor 3	0.34341	0.21246	0.1630	1.1066
Factor 4	0.13095	0.48662	0.0621	1.1688
Factor 5	-0.35567		-0.1688	1.0000

LR test: independent vs. saturated: $chi^2(10)$ = 47.81 Prob>chi^2 = 0.0000

The earlier perception result data mentioned in Tables 4.35–4.39 further analysed by principal factor method results obtained represented by Table 4.56.

Table 4.56. Factor Loadings (Pattern Matrix) and Unique Variances

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Uniqueness
D1	0.0699	-0.8016	0.0853	0.0288	0.3445
D2	-0.6985	0.1496	-0.2013	-0.1469	0.4275
D3	-0.2827	0.3622	0.2778	0.2340	0.6569
D4	0.4531	0.3162	0.2745	-0.2055	0.5771
D5	0.5088	0.2352	-0.3782	0.1074	0.5312

The first and second factors explain approximately 94% variation in the data. In addition, factor loadings of factors 1 and 2 demonstrate that according to the first factor, two important factors for improvement and safety of highway design are genuine maintenance, safety consideration to minimise accidents. However, when we include factor 2, miscellaneous utilisation of highway drainage water and consideration of water disposal at highway curves are also included in the first four important variables. However, the common variables are requirement of genuine maintenance and safety consideration.

Hence, three important factors for improvement and safety of highways design are proper drainage, genuine maintenance, and safety consideration. Road safety depends indubitably on the support and action of all stakeholders including government, civil society organisations, and road users. India's road fatalities are probably the highest with some improvement in safety conditions in the recent years. However, increasing traffic congestions are still perceived for the future. NHs account for higher number of deaths due to road accidents compared to other roads in recent years.

4.11 MODEL TESTING DATA RESULTS

A detailed analysis was further conducted on highway drainage, maintenance and safety to understand some of the major factors of road safety apart from routine highway design systems. During primary data analysis, informal discussions held among engineers and highway users, during the survey, have been used to elicit the various features of the highways because they did not reveal much information in the formal interview.

Traffic, highway maintenance, accidents and rainfall data of the study area were analysed to prove the hypothesis regarding highway drainage modelling for optimum maintenance and safety. The data collected on the highway connecting Jaipur city to Delhi were further used for analysing variance to obtain regression coefficient results.

The year-wise monthly data used in the regression model analysis are presented in Tables 4.57–4.60 showing details of number of vehicles, accidents, rainfall, and maintenance cost of the selected highway stretch. The results showed that with the gradual increase in the number of vehicles, accident rate and maintenance cost fluctuate. However, the rainfall data show high fluctuations, with some months recording almost nil and other months recording as high as 360 cm of rainfall. The data are presented yearly in Figures–4.26.

Figure 4.23 presents variation in secondary data during 2008 (Table 4.57) to understand the trends of monthly variation.

Table 4.57. Highway Traffic, Rainfall and Monthly Maintenance Cost and Accident Data (2008)

Year	Month	Vehicle (in lacs)	Accident (in hundred)	Rainfall (cm)	Maintenance (in lacs)
2008	January	36	4.0	0	28
2008	February	55.9	12	0	40
2008	March	57.3	13	0	42
2008	April	60	13	13	40
2008	May	58.8	13	87	40
2008	June	36.2	15	356	41
2008	July	56.6	15	123	40
2008	August	52.4	17	208	42
2008	September	55.9	17	237	45
2008	October	54.1	18	0	42
2008	November	56.9	19	0	40
2008	December	55.5	2	0	43
		635.6	176	1024	483

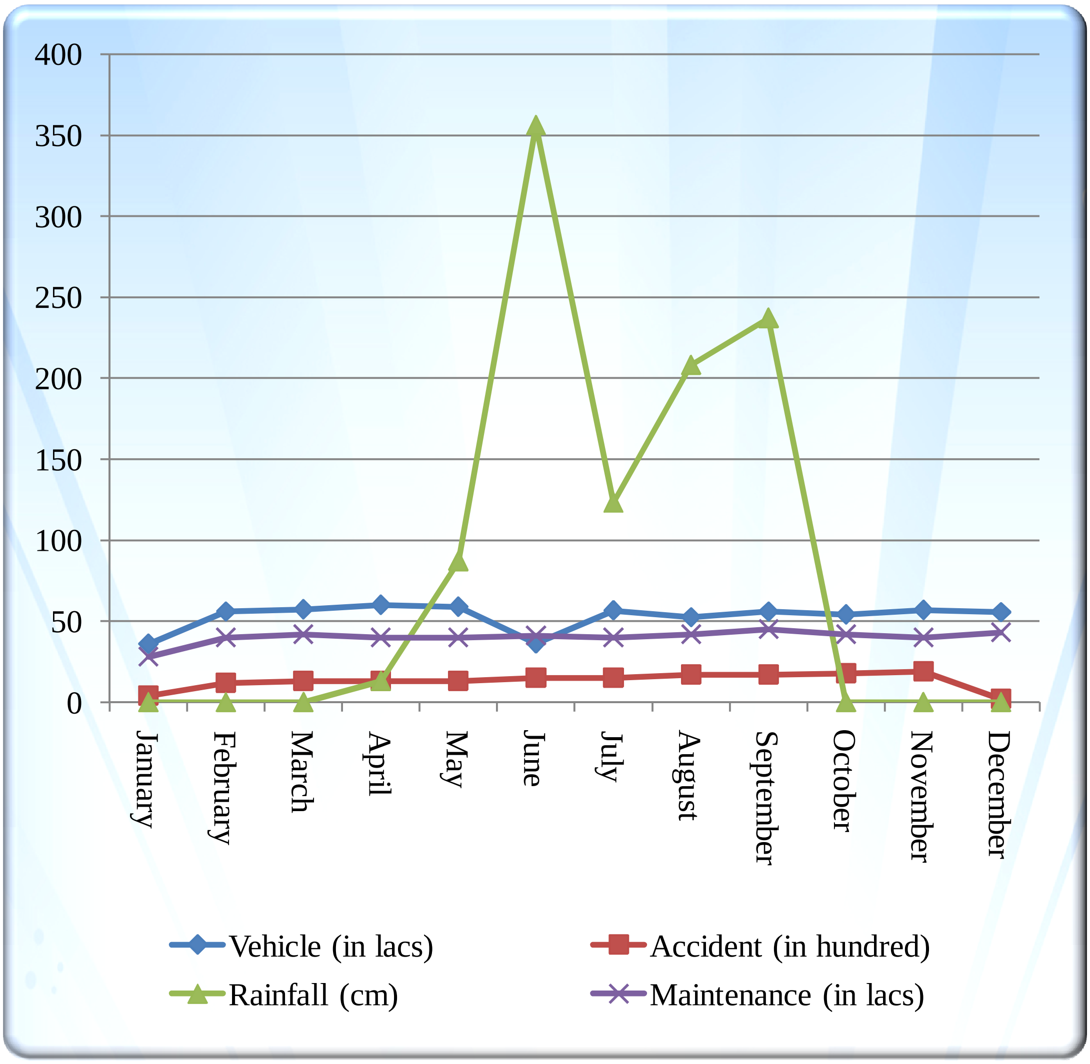


Figure 4.23. Monthly Data of Vehicle, Accident, Rainfall and Maintenance Cost (2008)

The rainfall is more effective during June–October (Figure 4.23) compared with other months. Increase in vehicles causes fluctuation in accident data and maintenance cost.

Table 4.58. Highway Traffic, Rainfall, Monthly Maintenance Cost and Accident Data (2009)

Year	Month	Vehicle (in lacs)	Accident (in hundred)	Rainfall (cm)	Maintenance (in lacs)
2009	January	59.7	18	0	40
2009	February	57.3	19	3	43
2009	March	55	20	10	42
2009	April	56.7	21	0	41
2009	May	56.2	24	19	31
2009	June	60.4	24	65	38
2009	July	55	25	147	30
2009	August	57.8	25	174	30
2009	September	61.9	25	147	30
2009	October	58.1	26	0	30
2009	November	57.7	27	12	30
2009	December	65.6	29	4	30
		701.4	283	581	415

Figure 4.24 is derived using Table 4.58 and represents graphical variation in data behaviour during year 2009.

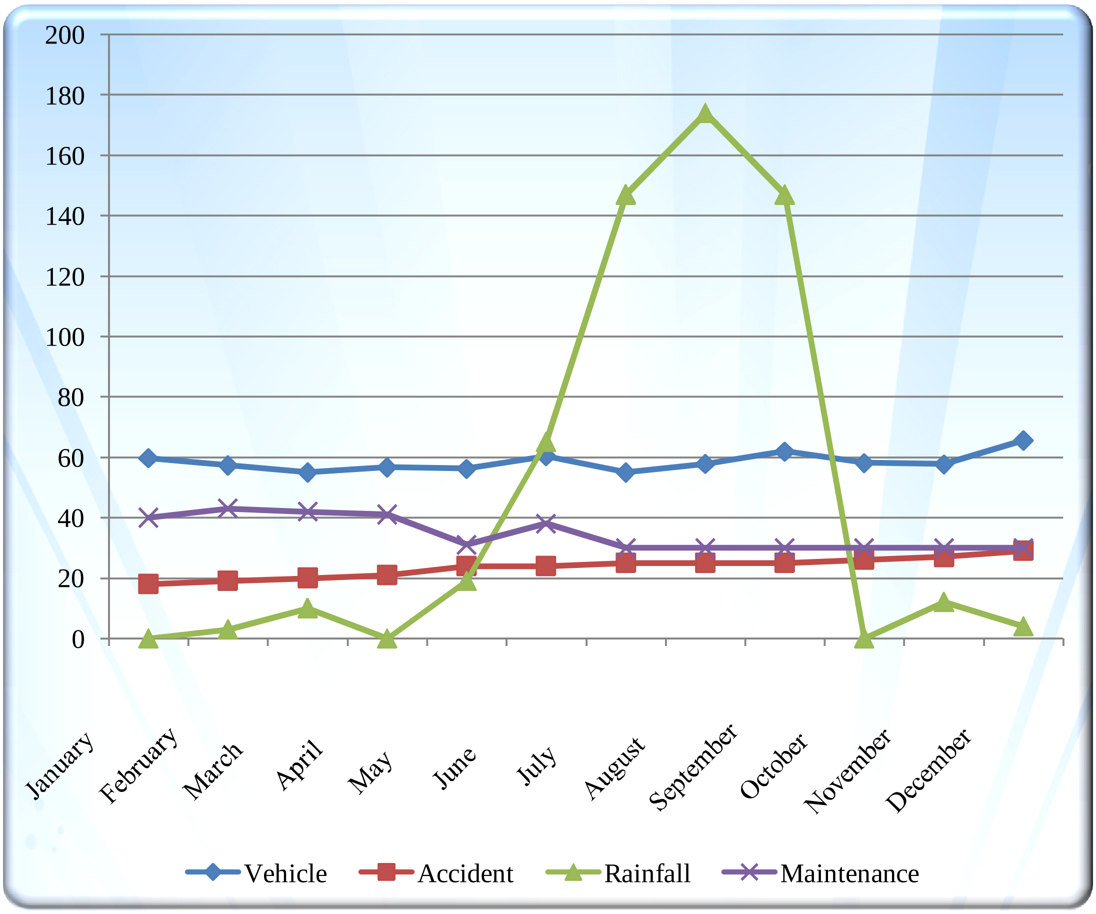


Figure 4.24. Monthly Data of Vehicle, Accident, Rainfall and Maintenance Cost (2009)

Figure 4.24 shows that rainfall is effective during April, June–October, and December compared with other months. The other variables do not show much fluctuations.

Table 4.59. Highway Traffic, Rainfall, Monthly Maintenance Cost and Accident Data (2010)

Year	Month	Vehicle (in lacs)	Accident (in hundred)	Rainfall (cm)	Maintenance (in lacs)
2010	January	63.8	19	7	40
2010	February	62.1	20	23	30
2010	March	67	24	0	32
2010	April	65.8	25	0	30
2010	May	67.3	28	0	30
2010	June	70.1	28	34	30
2010	July	67.6	28	137	40
2010	August	67.8	29	250	30
2010	September	70.3	29	360	30
2010	October	66.3	30	5	30
2010	November	70.7	33	37	30
2010	December	74.4	33	4	30
		813.2	326	857	382

Figure 4.25 is derived using Table 4.59 to understand the variation and behaviour of monthly data during 2010.

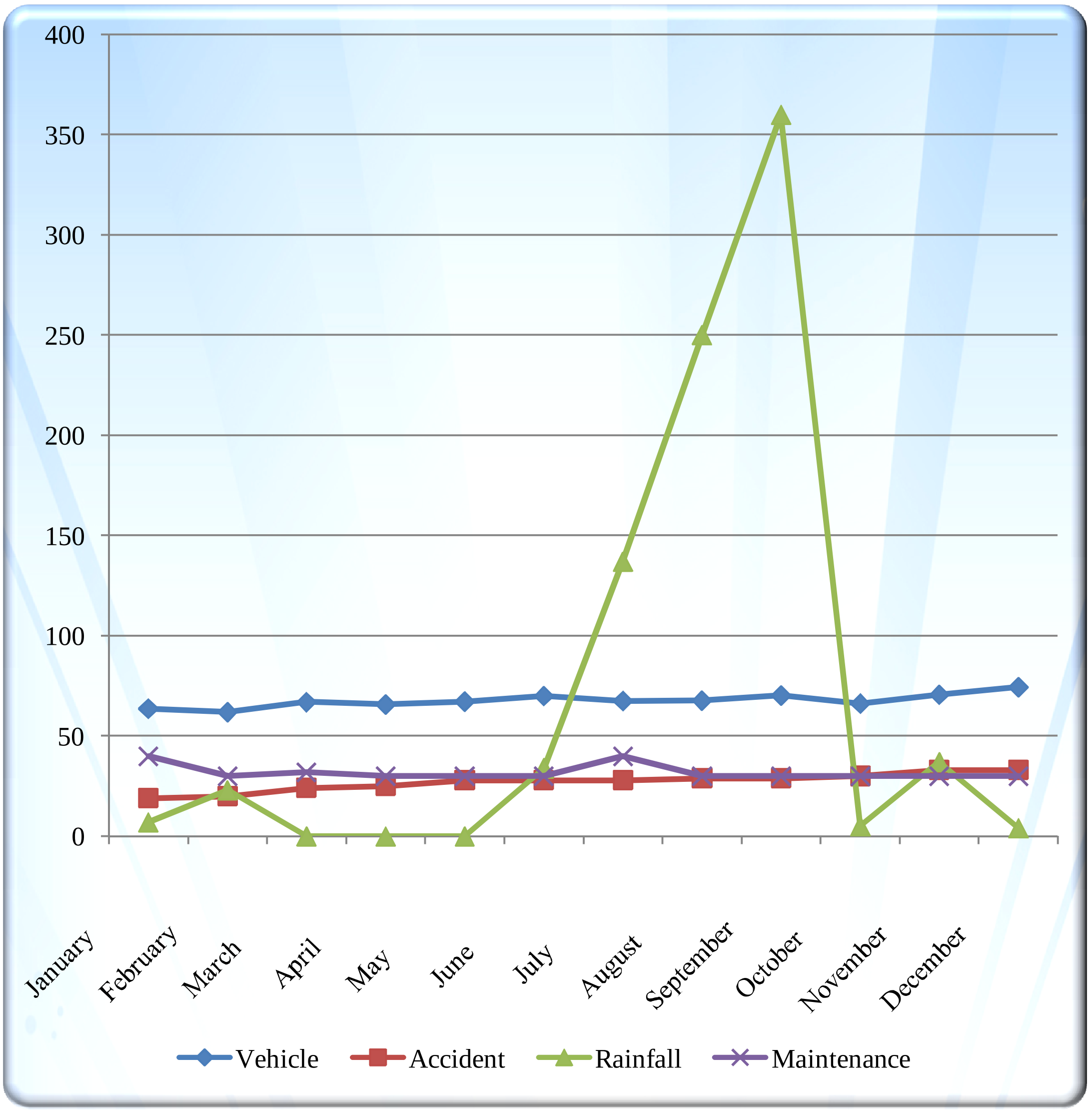


Figure 4.25. Monthly Data of Vehicle, Accident, Rainfall and Maintenance Cost (2010)

Figure 4.25 demonstrates that the rainfall is significant during July–September and slightly in January, February, and December. The value of the other variables show an increase compared with those of the previous years.

Table 4.60. Highway Traffic, Rainfall, Monthly Maintenance Cost and Accident Data (2011)

Year	Month	Vehicle (in lacs)	Accident (in hundred)	Rainfall (cm)	Maintenance (in lacs)
2011	January	75.1	22	0	30
2011	February	70.1	25	43	30
2011	March	72.3	26	0	30
2011	April	71.2	26	0	32
2011	May	71.7	26	21	40
2011	June	73.8	28	80	30
2011	July	75.9	28	127	30
2011	August	72.4	31	259	30
2011	September	73.9	32	283	30
2011	October	71.5	37	0	30
2011	November	73.5	38	0	30
2011	December	72.6	41	0	31
		874	360	813	373

Figure 4.26 is derived using Table 4.60 and represents monthly traffic data, mainteance cost, accident data, and rainfall to undertsand variations during year 2011.

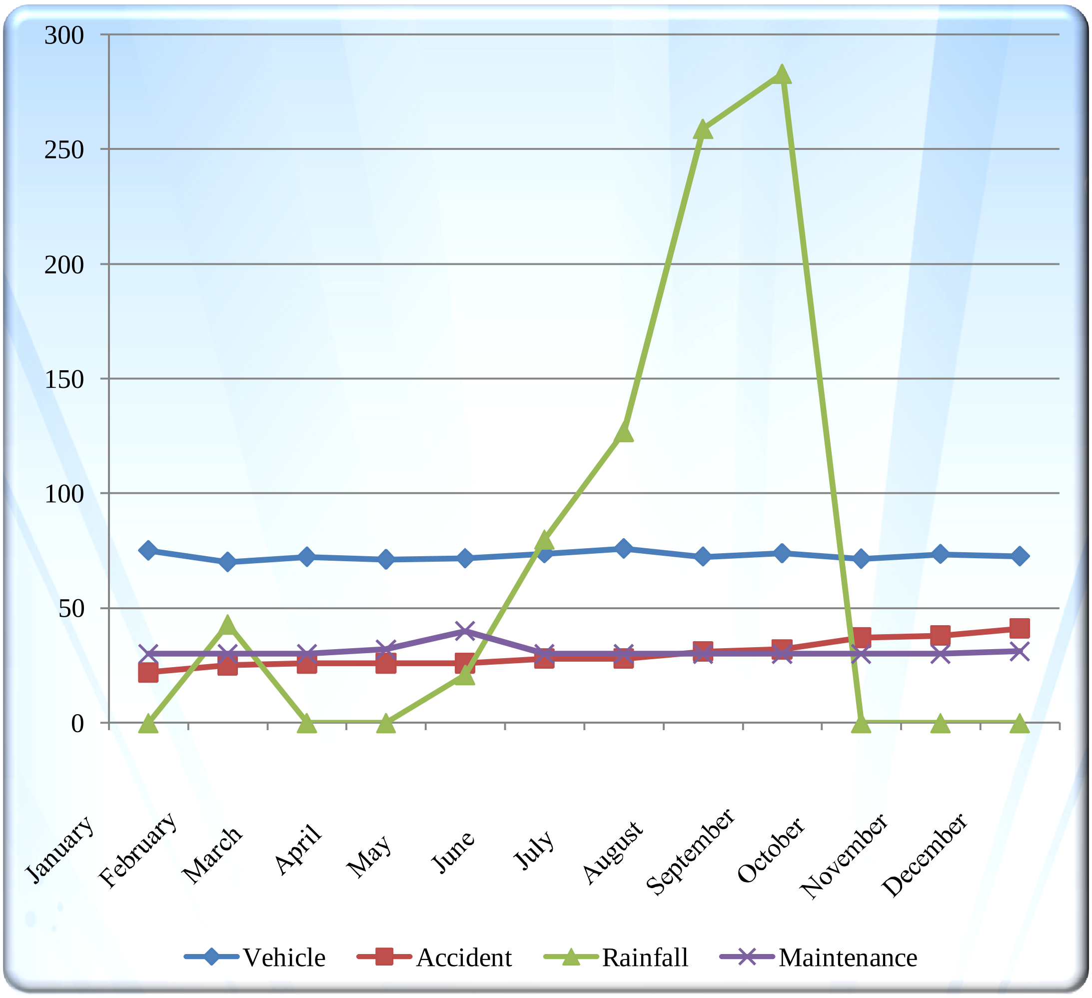


Figure 4.26. Monthly Data of Vehicle, Accident, Rainfall and Maintenance Cost (2011)

Figure 4.26 shows rainfall having considerable effect during July–October, anda slight effect in February and March; its shows almost nil effect in the other months. The other varibales except mainteance cost demonstrate an increase.

Furthermore, the yearly secondary data of NH-8 are also represented inTable 4.61,which describes accident data as dependant variable and number of vehicles, mainteance cost, and annual rainfall asindependent variables to obtain meaningful results (Report of rainfall data 2012; Traffic operation data expressway).

Table 4.61. Year-Wise Variation of Highway Operation Data for NH-8

Year	No. of Vehicle (in lacs)	Maintenance in cost (in lacs)	Accident (in thousand)	Rainfall (cm)
2008	635.60	483.00	176.00	1024
2009	701.14	415.00	283.00	581
2010	813.20	382.00	326.00	857
2011	874.00	373.00	360.00	813

Figure 4.27 derived by using Table 4.61 represents yearly variation of secondary data of NH-8 to compare rainfall, maintenance, and accident due to vehicular activities, for studying the inter-relationship among variables by considering accidents data as dependant variable. Highway drainage depends upon rainfall data because of non-availability of other conditions. The rainfall was measured in centimetres and was considered as a drainage variable in the analysis. The maintenance cost and number of vehicles were considered in lakhs for calculation of regression results.

The secondary monthly data was analysed in terms of number of vehicles, maintenance cost and rainfall (as independent variables) and accident data (as dependant variables). The data variation shows that as the number of vehicle increase, accident and maintenance cost show a gradual fluctuation, and the rainfall shows high fluctuations.

The significant relationships among the aforementioned variables were examined using multiple regression analysis and coefficient results to prove hypothesis of research objectives.

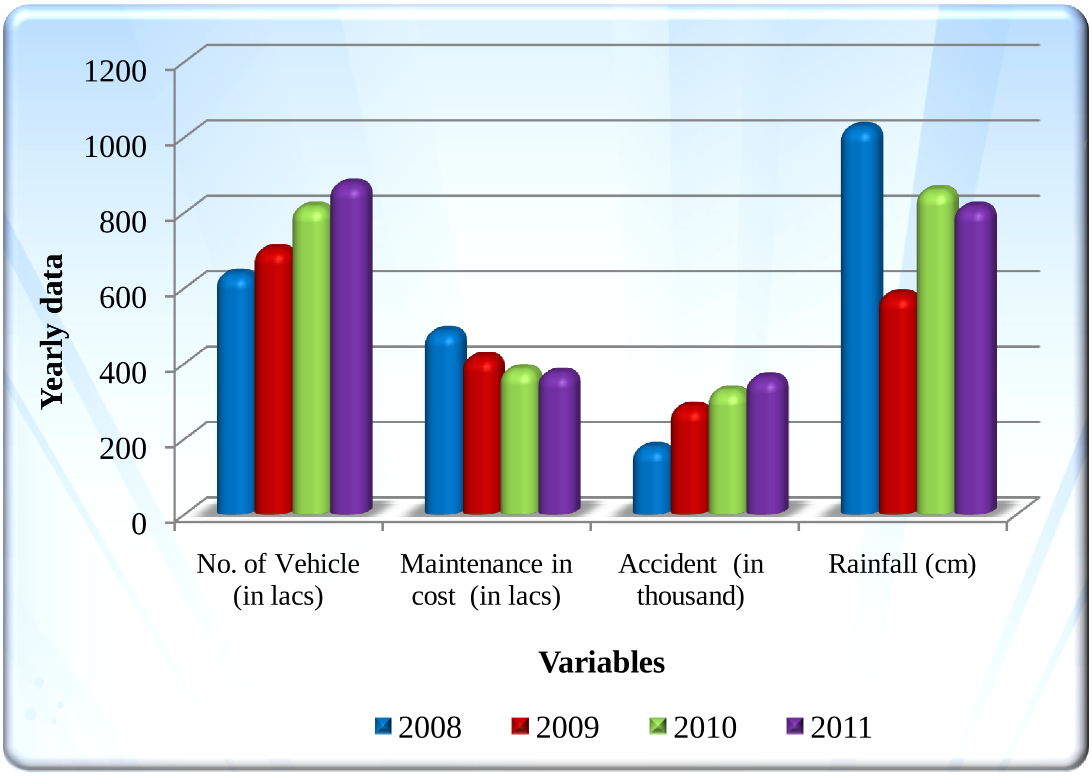


Figure 4.27. Year-Wise Comparative Variation in Highway Operation Data on NH-8

4.12 STATISTICAL ANALYSIS ON HIGHWAY DRAINAGE MAINTENANCE AND SAFETY

Statistical critical analysis is performed on highway drainage, maintenance and safety by selecting dependant and independent variables on the basis of research methodology. In absence of proper drainage data rainfall is taken to achieve the correlation effect among highway drainage, maintenance and accident data. Model testing observed to examine the confidently of secondary datas. Further analysis of variance performer on result of model summary by selecting predictors and dependent variables. Thereafter regression coefficient established for validation of results observed during perception survey data in next successive paras.

4.12.1 Testing of Model

Table 4.62 summarises the results of model testing of R^2(0.697) and R^2-adjusted(0.677) of the regression model. *R* represents the multiple correlation coefficients between the observed and predicted values of the dependent variables. Larger values of *R* indicate stronger relationships. Table 4.62 indicate multiple correlation coefficient square results are the same with high value of *R* (0.835). R^2 is the proportion of variation in the dependent variables explained by the regression model. It helps determine the model fit of the data. Again, a larger value of R^2 (0.697) in the output shows that the model fits the data well. R^2 tends to optimistically estimate how well the models fit. In contrast, R^2-adjusted attempts to correct R^2 to reflect the goodness of fit of the model more closely in the traffic data. However, models with too many variables are often over fit and difficult to interpret, which is not true in our case because of only three independent variables.

Table 4.62. Model Summary

Statistics	R	R^2 given	Adjusted R^2
Results	0.835	0.697	0.677

Predictors: (Constant), Maintenance Cost, Rainfall, Vehicle
Dependent Variable: Number of Accident

4.12.2 Analysis of Variance With Accident Data

Table 4.63 presents the result variance analysis of the regression model. The sum of squares, degrees of freedom, and mean square are displayed for two sources of variation, regression, and residual. The output for regression displays information about the variation accounted for by the regression model. ‘Total’ represents the sum of the information for regression and residual. A model with a large regression sum of squares in comparison to the residual sum of squares indicates that it accounts for most of the variation in the dependent variables. Very high residual sum of squares indicate that the model fails to explain a high variation in the dependent variables. The results clearly indicate that regression sum of squares value is 17.632, which is higher than the residual sum of squares of 7.653 indicating that the model accounts for most of variation in the dependent variables.

The mean square is the sum of squares divided by the degrees of freedom. The *F* statistic is the regression mean square (MSR) divided by the residual mean square (MSE).The regression mean square for degrees of freedom is the numerator of and the residual mean square for degrees of freedom, which is the denominator for *F* statistic. The total number of degrees of freedom is the number of cases minus 1 (n − 1). If the significant value of *F* statistic is smaller than, say, 0.05, then the independent variables effectively explain the variation in the dependent variable. If the significant value of F is larger than, say 0.05, then the independent variables do not effectively explain the variation in the dependent variable. If the significant results of *F* value is smaller than 0.01,the independent variables effectively explain the variation in the dependent variable, which is also termed as highly significant or significant at 1% level.

Table 4.63. Analysis of Variance (ANOVA) for Accident Data

	Sum of Squares	**Degree of freedom (Df)**	**Mean Square**	**F test**	**Significanc e**
Regression	17.632	3	5.877	34.557	0.000
Residual	7.653	45	0.170		
Total	25.285	48			

Predictors: (Constant), Maintenance Cost, Rainfall, Vehicle

Dependent Variable: Number of Accident

The aforementioned results clearly indicate significance of *F* is (0.000) such that the model fits well to the data, and independent variables also effectively explain variation in dependent variables.

4.12.3 Model Coefficient

The coefficients of the estimated regression model presented in Table4.64 show that the number of vehicles has a positive *t*-value (+ 7.087) and a statistically significant relationship with the number of accidents. This implies that increasing number of vehicles cause more accidents. Another variable cost of maintenance showing negative *t*-value (− 4.475) and statistically significant relationship with the number of accidents indicates that if the cost of maintenance declines, the number of accidents increases, which in turn indicates that if highway maintenance is not proper, more accidents occur because of poor road condition and increasing number of pot holes and cracks.

Table 4.64. Regression Result (Coefficient) with Accident Data

Number of accident dependent variable	Coefficients		t-value	Significance
	Regression coefficient (B)	Std. error		
(Constant)	1.795	0.602	2.979	0.005
Vehicle	0.038	0.005	7.087	0.000
Rainfall	0.004	0.001	1.164	0.050
Maintenance cost	-.052	0.012	-4.475	0.000

The rainfall variable shows positive *t*-value (+1.164) relationship with moderately significant data of the number of accidents. The lower value of *t* is because the study area in Rajasthan largely remains dry throughout the years and even if it rains, water remains on the road for a longer period and damages the highway.

The results of study areas show that the gradual increase in the number of vehicles cause the accident and maintenance cost to fluctuate. Rainfall fluctuated severely with some months showing almost nil and other months showing as high as 360 cm. The increase in the number of vehicles creates chaos, traffic jam, and difficulty in traffic management because of limited road length and lack in number of traffic personnel and traffic sense among the vehicle drivers. The study results are confident up to significance levels 0.000. The variable, cost of maintenance, shows negative and statistically significant relationship with the number of accidents indicating that if the cost of maintenance reduces, the number of accidents increases. The study results are confident up to 100% for significance levels 0.000. The rainfall variable shows positive relationship with accidents indicating more rains and resulting in more accidents. The results are meaningful up to significance level 0.050.This reflects the need of proper drainage system on the roads. However, maintenance and traffic management showed statistically stronger results compared to rainfall in the study area being in arid zone.

The engineer also elicited some of the challenges they might face in future such as the growing use of telecommunication and other technology, for example, route guidance, infotainment, and cell phones in vehicles is distracting drivers.

CHAPTER 5
CONCLUSIONS

The research was carried out by using a well-designed questionnaire with statistical data analysis and validation. The research on highway drainage for maintenance and safety is a case study on the interconnecting highways of Jaipur city. The features and variables were identified for perception survey. The statistical analysis was carried out by using Kendall correlation coefficient and factor analysis. Regression model study and analysis of variance was applied for validating results.

The following are the conclusions drawn from research.

1. The results on the basis perception survey and Kendall correlation analysis among good and bad features for 95% to 99% significance level are represented in Table No. 4.47. It is concluded that the good features proper surface drainage, good riding surface, surface camber, regular maintenance and safety, proper traffic management, and highway crust no failure are significantly co-related in highway design system.
2. The Kendall correlation result among bad features represented in Table No. 4.48. It is concluded that bad features in present design system highway submergence, improper maintenance schedule, improper highway safety, improper drainage of highway curves, poor traffic management, improper drainage, irregular renewal are significantly correlated in highway design system.
3. Further on the basis of perception data survey analysis results revealed that 74% of respondents perceive consideration of water disposal on pavement

surface with curves and minimum retention time to be essential features for highway design system.

4. Data analysis of perception survey represent 70% of the respondents favour safety consideration to minimise accident, ribbon development, and genuine maintenance so these are considered essential features for future alternate highway design.
5. On the basis of accident severity analysis, road safety efforts were concluded as being mandatory for minimising accidents on highways.
6. The results obtained through perception data analysis indicate that proper traffic management, highway safety, and highway in submergence have an important role in highway design. In addition, improper drainage causing pot holes, stagnant water on surface and construction defects are factors cause by poor maintenance of highways.
7. Stakeholder perception show that consideration of water disposal at highway curve, drainage maintenance due to ribbon development are important factors to be considered in future highway development projects.
8. The perception survey of highway drivers and users revealed that lack of traffic management, improper maintenance of highways, and absence of drainage are essential factors.
9. Furthermore, according to the perception survey high frequency of maintenance, disposal of water near curves and medians, minimum water retention time on highway surface and provision of water storage with harvesting wells should be given significant consideration in highway design systems.

10. The results of factor analysis with significant Eigen value and positive factor loading conclude that:

    (i) Proper traffic management, good riding surface, and proper drainage system are the three most important 'good feature' variables for highway design improvement.

    (ii) Poor traffic management on highway, improper highway safety schedule, and highway in submergence are 'bad feature' variables for highway design.

    (iii) Improper drainage with pot holes, stagnant water on surface, design and construction defects are the important causes of poor maintenance of highways.

    (iv) The present highway design should be improved for future drainage situations, genuine maintenance and safety considerations.

11. The coefficients estimated using regression model data analysis of variance with regression analysis conclude that:

    (i) Number of vehicles have a positive relationship with number of accidents, representing positive *t*-value (+ 7.08) indicating increase in the number of vehicles, which in turn leads to unsafe highway conditions and difficulty in traffic management due to limited capacity road width and lack of number of traffic personnel and traffic sense among the vehicle drivers;

    (ii) The variable, cost of maintenance, shows negative relationship with number of accidents representing negative *t*-value (–4.475). It indicates that if highway maintenance is improper, more accidents occur as a result of increasing number of pot holes and cracks. The data analysis study concluded that with the number of vehicles rising gradually, accident and maintenance cost fluctuates. The increase in the number of vehicles creates chaos and traffic jam.

(iii) The rainfall variable represents positive relationship and moderately significant data of the number of accidents having poor *t*-value, that is, + 1.164. The study area of Rajasthan largely remains dry throughout the years and even if it rains, water remains on the road for a longer period due to poor drainage and damages roads.

However, maintenance and traffic management showed statistically stronger results compared to rainfall in the study area.

SCOPE FOR FUTURE STUDY

This study has can be further extended on the following points:

- The primary data may be validated using secondary data by considering another highway location stretch.
- The correlation between perception of stake holders can be established to optimise highway drainage for future research.
- Highway design modification should be carried out as per perception survey and necessary impact may be assessed quantitatively.
- The highway officials elicited some challenges they might face in future such as the growing use of telecommunication and other technology, for example, route guidance, infotainment, and cell phones in vehicles, which are distracting and needs to be studies further.
- The transportation variables including distance travelled, which is defined as the number of trips in transportation, road environment, number of motorised vehicles, and traffic may be considered as research factors in future studies.
- The analysis of discussion with highway officials suggest that proper designing of roads for improving road safety (Safety Engineering) and future systematic research are required to implement the road safety programme successfully.
- A comprehensive future quantitative research should be conducted on factors that cause accidents and deaths such as human errors, neglect in driving or irrational driver behaviour, infrastructure problem, inadequate roads resulting in high concentration, road width and state of shoulders, median.
- The maintenance cost with proper implementation plan, proper traffic management, and awareness of road users are required in future systematic research to obtain quantified data of safety.

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Annexure -1

(a) Questionnaire 1: Highway Maintenance and Safety

प्रश्नोतरी नम्बर 1

(सर्वेक्षण हाइवे मरम्मत, सुरक्षा के बारे में)

1 हाईवे उपयोग करने वाले व्यक्ति का नाम

टेलीफोन नं.

2 वार्तालाप / स्थान / सर्वेक्षण

3 वर्गीकरण हाइवे उपयोगी

4 हाइवे पर चलने वाले वाहन के सन्दर्भ में सूचना

(अ) वाहन / गाड़ी के माहवारी रखरखाव खर्चा

(ब) क्या उक्त खर्चा कम किया जा सकता है

(स) यदि हां तो मरम्मत कम करने के उपाय

(i)	हाइवे सड़क स्थिति	%
(ii)	ड्राइवर आदत	%
(iii)	वाहन / गाड़ी की उम्र मय निर्माण वर्ष	%
(iv)	वाहन / गाड़ी की सामान्य मरम्मत अनुमानित	%
(v)	ईंधन की स्थिति अनुमानित खर्चा मासिक	%
(vi)	अन्य कारण	%

(द) हाइवे पर चलने वाले वाहन रखरखाव निर्भरता

(i)	हाइवे मरम्मत	%
(ii)	हाइवे पर पानी निकास व्यवस्था	%
(iii)	हाइवे उपरी व सतह स्थिति	%
(iv)	हाइवे ज्यामिती (मोड़ इत्यादि)	%
(v)	हाइवे पर दुर्घटना रहित चलने	%
(vi)	अन्य कारण	%

5 हाइवे सुरक्षा सर्वेक्षण

(क) क्या पिछले एक साल में आपने दुर्घटना का सामना किया है ?

(ख) यदि **हां** तो कितनी बार

(ग) दुर्घटना का प्रकार

(घ) दुर्घटना के मुख्य कारण

(i) यातायात प्रबन्धन कमी

(ii) उचित समय पर हाईवे मरम्मत

(iii) सड़क सतह पर पानी निकास नहीं होने सें पैच मरम्मत

(iv) ड्राइवर की लापरवाही

(v) वाहन के अप्रयाप्त रखरखाव

(vi) अन्य कारण

(च) उक्त दुर्घटनाओ को टालने के कोई पांच उपाय (प्राथमिकता आधार पर)

(i) समय पर हाइवे सड़क मरम्मत

(ii) हाइवे पानी निकास माकुल व्यवस्था

(iii) समय समय पर हाइवे लेन मार्किंग/साइन बोर्ड

(iv) हाइवे पर रोशनी उचित प्रबन्ध

(v) यातायात उचित प्रबन्धन

(vi) अन्य कारण

6 दुर्घटनाओ में अनुमानित नुकसान की स्थिति

सीधे तोर पर

1. वाहन क्षति
2. जान माल क्षति
3. प्राथमिक उपचार व्यय
4. अन्य व्यय

असाधारण तोर पर

1. हाइवे जाम देरी
2. उपचार खर्च
3. चोटिल/मृत्यु की स्थिति में भविष्य में नुकसान
4. अन्य व्यय

Questionnaire 2: Drainage, Maintenance and Safety

Questionnaire No. 2		
(Perception for PhD research work on highway drainage for maintenance and safety)		
a	Name and Telephone No. of respondent :-	
b	Place of Interview	
c	Category of Respondent	
(i)	Highway Engineer	(ii) Highway Officials
(iv)	Traffic Police	(v) Any Other
1	**Is Present Highway design is OK reply in Yes or No**	
a	**If 'Yes' what are the good features of present Highway road design**	
i	Proper drainage of water	
ii	Good Riding surface	
iii	Highway crust no sign of failure	
iv	Proper Traffic management lane wise	
v	Regular maintenance and safety schedule followed	
vi	Any other reason	
b	**If 'No' what are bad features in present Highway road design**	
i	Highway in submergence	
ii	maintenance schedule is improper	
iii	Highway safety schedule is not proper	
iv	Drainage of high median and curves is not proper	
v	Poor traffic management on highway	
vi	Any other reason	
2	**Reasons of poor condition of maintenance on highway**	
i	Drainage is not proper, in hence to develop pot holes/Patches	
ii	Surface camber allow stagnant water on pavement	
iii	Regular Renewal is not being applied	
iv	Design/construction defects appearance on highway surface	
v	Any other reason	
3	**Opinion about present Highway drainage system**	
a	**Is drainage system proper……narrate…….**	

	Yes 1 or No 2	
b	**If 'yes' three main characteristics**	
i	Proper disposal of water	
ii	Disposal of water at curves and medians	
iii	Embankment height above G. L.	
c	**If 'NO' narrate main problems**	
i	Improper maintenance	
ii	Choking of drains	
iii	Embankment in submergence	
iv	Ribbon development along highway	
v	As per highway geometrics disposal of water not proper	
d	**Provide three main suggestions to improve problem on highway traffic**	
i	Minimum retention time to drainage high water surface	
ii	Disposal of drainage water at curves and medians may be utilised for Tree plantation	
iii	Consideration ribbon development	
4	**Maintenance strategy of Highway**	
a	Highway maintenance approx. cost per Km	
b	Frequency years of maintenance	
c	Type of routine maintenance month	
5	**Please give your suggestion for present highway road design or provide alternate design for improvement safety and maintenance**	
i	Consideration ribbon development	
ii	Consideration of water disposal at Highway curves	
iii	Miscellaneous utilisation of Highway drainage water	
iv	Safety consideration to minimize accident	
v	Genuine maintenance required	
6	**Please tell your opinion about present highway drainage maintenance and safety entering/emerging Jaipur City**	

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