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A Review of Highways Geometric Design to Ensure Road Health and Safety

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Abstract— *The amount of Highway accidents that has resulted to death and fatal injuries and incapacitation is a call for concern. While some of the causes of these accidents have been attributed to negligence and poor driving, some has been attributed to failure of certain aspects or factors during the geometric design process. Analysis and proposals have been given on how to limit road accidents and injuries and thus make an important contribution to road safety. Through literature, this paper has tried to identify the problems of road health and safety which could be solved using engineering principles. Current standards of highway design are focused on the enhancement of the safety of the road users, their comfort and convenience and making endeavours to meet up with the health and safety needs and societal mobility. During the highway design process, problems such as economic, managerial and construction problems are usually encountered. Some of the tools use in solving some of the problems are reviewed here. This paper duel on two major issues that could be duel on to ensure safe roads. These two major aspects are: the engineering aspect of safe road infrastructure design and the enhancement of road safety from the engineering perspective. A systematic approach to establish safety principles of engineering and traffic management is discussed and highlighted that the detail analyses of accidents for the identification of main problems form an essential part of engineering for safety. It identifies the main road problems that contributes to road accidents and advice on what need to be done by stakeholders when developing strategies and policies and designing safe roads to eliminate accidents and injuries. The paper highlight that the making of safe highways or roads is a shared responsibility between the designers/operators of the road system and the road users and point out the factors that can form a safe system and how a sustained improvement in road safety can be delivered. The paper presents the Key Elements of Safe Road Infrastructure Design.*

Keywords— *Highway, Road, Health, Safety, Design, Geometric, Accident, Vertical, Horizontal, Alignment, Engineering, Construction, Injuries, Death, Traffic, Infrastructure.*

I. INTRODUCTION

Road safety is one of the most important aspect taken into consideration when designing highways. The health and safety of all users must be given priority. While designing a highway that maintain environmental and aesthetic quality, the highway must equally be efficient and safe and the economic traffic operations must also be adhere to. The characteristics of the traffic, vehicle and driver greatly influence the geometric design of the highway. There is constant or regular updates or changes in highway geometric design due to regular changes in the traffic, driver, and vehicle characteristics. These designs are updated to meet up with the changes in these characteristics by the implementation of certain policies.

There is need to evaluate new design methods that will improve road safety and develop approaches that can help in the evaluation of those safety majors.

The importance of developing a proper guideline and highway geometric design is imperative as these guidelines serve as starting point when a road design project is initiated. Most countries have their own highway geometric design guidelines. The overall objective of the different design guidelines is to design a highway that is safe and fit for purpose.

The design of safe roads has become an issue of concern globally because of the number of deaths recorded because of road accidents that occur around the world. According to Kapila *et al.,* (2013) an estimation from the World Health Organisation (WHO) shows that while an estimated 1.3 million die each year because of road accidents and it is the number 1 cause of death for young people worldwide, 50 million people are injured yearly, and many of them are left disabled. These road accidents cost a fortune to the global economy to a tune of about $1.2 trillion each year and is the highest cause of global injuries. According to Lamm *et al.*, (1988) most of these accidents occur in two-lane, rural Highways in the United States of America. As cited by Lamm *et al.*, some experts like Hayward (1980), Hayward *et al.*, (1985), Hiersche (1987), Leisch and Leisch (1977) and Koeppel and Bock (1979) have attributed the leading cause of these accidents to the sudden changes in operating speed because of horizontal alignment. According to Cirillo (1984) as cited by Lamm *et al.*, (1988), to curb this, the state and federal agencies spend about 2 billion dollars every year just to restore, rehabilitate and resurface the roadways.

It is because of this that Kapila *et al.,* (2013) advice for the need of concerted efforts to begin at the ground level to avoid these number of accidents that results to many lives lost and financial expenditure to the economies around the world.

The United Nations (UN) saw the need to consider the Road Safety as an issue of great concern. As asserted by Kapila *et al.*, (2013) as a call for concern, decade 2010 – 2020 was declared by the UN as the decade of Action for Road Safety. The International Road Federation (IRF) also took some majors toward road safety and developed Road Accident Data Recorder (RADAR) that helps to store data systematically and helps analyse accidents in a scientific manner. Data from RADAR can be used by all the stakeholders such as health professionals, insurance companies, policymakers, researchers, road engineers, vehicle manufactures, lawyers, policymakers, non-governmental organisations and community groups, politicians and education and awareness groups who are involve in Road Accidents. As further asserted by Kapila *et al.*, (2013) this RADAR system that produce secured and scientific data road accidents will transform aspects of road safety including road safety engineering in a positive way.

II. Literature Review

Highways are the large motorways that link different parts of the land and forms major part of the transportation network which facilitate trade between people and establishes civilisation. They form a major part of transportation corridor in developed countries.

While geometric design can be described in simplistic term as an exciting trend that focuses on the basic beauty of mixing certain curves, shapes, and lines together for creative results using mathematical principles, Easa (2003), describe geometric design of highways in a more professional manner as the design of the visible dimension of the highways features such as both vertical and horizontal alignments, bicycle and pedestrian lanes, cross sections, and intersections. This design involves some fundamentals and concepts (such as the type of highway, highway curves, site distance and design controls) that guide and control the way highways are designed.

Current standards of highway design are focused on the enhancement of the safety of the road users, their comfort and convenience and making endeavours to meet up with the health and safety needs and societal mobility (Eluru *et al.*, 2018). The proposed highway design process involves a preliminary study of the site or location and an environmental impact assessment which normally involves a team of professionals including engineers, ecologists, planners, sociologists, lawyers, and economists with the responsibility of addressing issues related to highway development prior to the final design. These issues may include land-use, environmental, community and social issues.

While the preliminary study of the site or location involves the collection and analysis of data, the determination of the preliminary vertical and horizontal alignments, the location of feasible routes and the evaluation process of the different routes to select the route, the environmental evaluation involves the environmental impact assessment of the project to several areas such as water and air quality, wildlife, noise, and socioeconomics. Eluru *et al.*, (2018) stress the full need for an environmental impact evaluation for alternative highway locations as highways may not only cause changes to migratory patterns and the degradation or loss of wildlife habitat, but it may also impact the socioeconomics such as the displacement of people and businesses and the removal of certain historical sites.

The design process involves the establishment of the design details for the agreed route and the finalisation of the vertical and horizontal alignments, drainage facilities and all other construction items.

During the process problems such as economic, managerial and construction problems are usually encountered and the multi-objective analysis is a popular tool use in solving many of these problems (Brauers *et al.*, 2008).

To develop and implement a methodology for multi-objective optimization of multi-alternative decisions in road construction, Brauers *et al.*, (2008) review some articles that deals with the multi-objective decision and assessment of road design alternatives described by discrete values. In their study, they selected the Multi-Objective Optimization based on the Ratio Analysis (MOORA) method with focus on a matrix of alternative responses on the objectives. Their study reveal that the concept of multi-objective optimization of road design alternatives can be used to determine the best road design alternative.

Brauers *et al.*, forces behind any decision-making activity are their values, beliefs and perception as they believe that these forces are responsible for the difference that exist between the present and a desirable state.

Brauers *et al.*, believes that in construction, there are different structures and processes, with different variables that have different development objectives and this help to complicate the decision-making process. The decision-making process on the different decision alternatives are further complicated by different interest and values of the different stakeholders.

According to Brauers *et al.*, (2008), the Multi-Objective Decision-Making (MODM) helps to facilitate the evaluation and selection of each alternative on the set of objectives. The selection process is further facilitated by objective outcomes as they provide the basis used to compare different alternatives.

Therefore, Brauers *et al.*, sees multi-objective techniques as an appropriate tool to be used to rank or select one or more alternatives from situation where there is a set of available options with multiple and conflicting objectives and interest.

MODM is also referred to as: Multi-Criteria Decision Analysis (MCDA); Multi-Dimensions Decision-Making (MDDM); Multi-Attributes Decision-Making (MADM) ***(ibid).***

According to Kapila *et al.*, (2013) there are two major issues that could be duel on to ensure safe roads. These two major aspects are: the engineering aspect of safe road infrastructure design and the enhancement of road safety from the engineering perspective.

This literature review will duel on these two major aspects.

A. Engineering Aspects of Safe Road Infrastructure Design

Kapila *et al.*, (2013) has described these engineering aspects of safe road infrastructure design as the "5Es" of Safe Road Operations. These are engineering, enforcement, education, encouragement, and emergency care. While Kapila *et al.*, consider the 5Es to be important, Verma *et al.*, (2011) sees engineering, enforcement and education which they term as the '3Es' to be the most important key aspects.

1) Engineering

Engineering safety on the road has been a major concern of highway authorities for decades. The improvement of skidding resistance of wet roads was the first engineering activity recorded in the 1930s as a measure of road safety (Sabey, 1995). A systematic approach to establish safety principles of engineering and traffic management was adopted only after the second world war. This approach involves the

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identification of problems which could be solved using engineering principles (*ibid*).

The statutory responsibility for safety was given to the local authorities in Great Britain sometime in the 1970s to develop safety engineering practice. The local highway authorities were charged with the responsibility of finding a means in reducing road accidents and casualties and put appropriate measures in place to prevent accidents through education and engineering. This led to the creation of a group of road safety officers and road safety engineers in each authority. While the road safety engineers are charged with the responsibility for improving the environment, the road safety officers are charged with the responsibility for education and training.

As stated by Sabey (1995), the detail analyses of accidents for the identification of main problems form an essential part of engineering for safety. This involves the identification of the people involved in the accident, when did the accident occurred and where and why did it happen. While Sabey cited that road factors account for up to 25% of road accidents, she cited the problems of poor design of layout or control at junctions, poor road markings and lighting, inadequate signing, road obstructions and slippery roads as the main road problems that contributes to road accidents. The Built Environment should be defined in a way that includes the road design and vehicle design. Verma *et al.*, (2013) sees the improvement of road safety using traffic engineering, geometric design of roads and transport planning as engineering measures that can be used to counter road accidents and injuries and make the road safer. Some governments like that of India has laid emphasis on the compulsory use of Road Safety Audit (RAS) for all highways as part of engineering measures for road safety ***(ibid)***.

The International Transport Forum (2015) recommend the design of self-explaining roads as this serve as a tool to help drivers adopt appropriate behaviour as this has been proven through pilot projects that it can help reduce road casualties by about 30%. The designed roadway should advice the road users and provide guidelines on what they should do to avoid accidents. The International Transport Forum (ITF) advice on the use of a more pro-active approach to road infrastructure design and management with serious consideration given to road safety in all stages of the road life cycle.

While Sabey acknowledge that majority of road accidents are caused by human errors, she said that effective engineering and traffic management practice can help influence road users to change their behaviour which can help make a safer environment through the reduction of conflicts. She further stresses the importance of engineers to understand the factors that human plays when investigating and diagnosing causes of road accident on a particular site as problems experienced by road users can give a good pathway to look for engineering solutions in the improvement of the behaviour of road users.

Sabey cited an example of a road junction where accidents were reported due to vehicles failure in negotiating a bend on the road as the junction presented a misleading visual problem that never alerted the drivers on the road and this help to cause accidents. Drivers attributed the cause of the accident to the fact that they couldn't see the information and warning signs as they focused their eyes on the distant view ahead. As an engineering solution to this problem, Sabey talked of the realignment of kerb line at the junction and the erection of black and white chevrons on the projecting area of the verge on the nearside. This help to break the 'straight-through' appearance of the road ahead and help the drivers to see the junction from a good distance well ahead of time. This helps to reduce the number of accidents there considerably.

2) Enforcement

The strict application and enforcement of laws governing highway safety is one of the right things to do to limit road accidents and injuries. Some of these accidents are caused by the physical disability like poor vision of the drivers. The physiological characteristic of any driver plays an important role in safe driving, thus the mandatory testing of the physiological characteristics of drivers before issuing driving licence in all countries will help to limit highway accident.

The obtaining of driving licence in certain countries like Cameroon where corruption is a canker worm at times doesn't matter if you passed the driving test or not but matter on who you know and the amount of money you have to offer to obtain the driving licence. This results to the issuance of driving licence to people who have never taken any formal driving education or passed driving test. It will be important to stem out these corrupt practices by enforcing laws to punish culprits.

Formal driving education and test should be mandatory and hazard perception test should be an integral and mandatory part of the practical test. Some countries like the United Kingdom use technology such Intelligent Transport Systems (ITS) to enforce traffic law. The system involves the use of surveillance cameras, vehicle-actuated traffic signals, enforcement cameras and centralised traffic management centres use to ensure traffic laws are respected to avoid accidents and improve road safety. The application and use of ITS in all countries will steer the issue of highway safety in the right direction.

Effective enforcement of traffic laws to all road users will limit road accidents and injuries and thus make an important contribution to road safety.

3) Education

Verma *et al.*, (2011) sees education as one of the countermeasures to address the road safety issues to limit the amount of road accidents and injuries. They cited the need to spread road safety awareness in schools, using media and traffic parks, banners, and hoardings, educating drivers, licensing, and training as some forms of education to be used. According to Verma *et al.*, driver's education is very vital as it helps in the improvement of their performance and responsibility as it helps them to know and adhere to the rules and regulations of road safety and gives them more consciousness.

Jonsson *et al.*, (2013) see the goal of driver education, the content and method of the education and the procedure of testing as the three main pillars of driver education that can be put together to achieve effectiveness. According to Nyberg (2007), the putting together or harmonisation of these pillars

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needs the involvement of well qualified instructors and knowledgeable examiners with competent teaching skills in the training of drivers. Mayhew (2007) posited that the issue of hazard perception, over reaction and slow response, risky and inappropriate behaviour, skill deficiencies, self-awareness, the context in which driving is done and driving errors are the focus of the curriculum of driver education in North America. Jonsson *et al.,* (2013) states that in Europe, while the curriculum for driver education for the theoretical test covers the following topics in order of priority; traffic regulations, behaviour towards others, vehicle technique, hazard perception, environmentally friendly driving and first aid training, training for the practical cover main topics like changing direction, driving away, reversing the car, safety car checks and mastery of traffic situations.

The Organisation for Economic Co-Operation and Development (OCED) (2006) notes that, driver training systems are more focused on vehicle control and execution of maneuvers. They advised that it is important to also place emphasis on route findings and self-assessment with higher levels of driver training as these can serve as effective measures to help counter road accidents and injuries.

It is very important all aspects of the training should be treated with equal importance from both the instructors and the learners.

As asserted by (OCED) (2006), the creation of competent drivers who are safe and environmentally conscious should be the main goal of the licensing process and drivers training.

Kapila *et al.,* (2013) advice on the need to teach and educate road users about good road behaviour through awareness campaigns. The International Transport Forum (2015), encourage the use of tools that includes guidelines, manuals, and software to support the Road Infrastructure Safety Management (RISM) as design standards alone cannot guarantee road safety in all condition. RISM is a set of procedures that support a road authority in decision-making when it comes to the improvement of road safety of a road network. ITF recommends the benchmark road infrastructure against good practices in different countries. While drivers and users should be constantly educated on the importance of the use of seat belts, non-alcohol and respect for speed limits, the implementation of programmes to improve road safety is important. Road safety programmes in different countries should be compared with practices elsewhere so that opportunities that could prevent fatalities and serious injuries can be identified.

4. *Encouragement*

Kapila *et al.,* (2013) recommend that people should be rewarded for good road behaviour. Bird and Tapp (2008) talked of the principle of self-interest – incentive-based campaigns and mentioned an example of the Keep Your Wheels campaign related driver safety amongst young scooter riders. This is an incentive appeal – based on the principle of self-interest led by Rothschild who believed that self-interest is the key driving force of behaviour, and that to obtain behaviour change you need to offer something that offers a higher value to the individual than the present behaviour, and this can be done in the form of an incentive.

According to Bird and Tapp (2008), it has been proven that incentives can work well in creating 'instant', short term, behavioural change in areas where such changes are quite easy to make.

Deshpande *et al.*, (2004) cited an example in the USA where Rothschild was responsible for the development of Road Crew – a programme in which working class men were offered subsidised taxi facilities to prevent them from drinking and driving.

According to Bird and Tapp (2008), incentives maybe effective but may be expensive and only work as a short-term measure or "bribe" to people which will not help to change their behaviour in a long term as future removal of the incentive will force people to go back to their old-time behaviour. Thus, they recommend events-based programmes that work 'on the ground' rather than remotely and suggested that a theme like 'real men drive like grown-ups – skillfully', where they are backed up with events at a driving centre offering subsidised advanced driving.

However, Bird and Tapp (2008) caution that, ideas aim at improving drivers' car handling need to be approached with great care otherwise such ideas may help to cause more accidents rather than prevent them.

5. *Emergency care*

Roadside medical care and access to paramedics in the "Golden Hour", or the hour immediately following a road accident during the provision of first aid can greatly increase the survival chance of the victim of the accident (Kapila *et al.*, 2013). According to the World Health Organisation as cited by Coats and Davies (2002), about 320 000 injuries, 40 000 serious injuries, and 3400 deaths occur every year in the United Kingdom caused by road traffic crashes. A third of the death of these road traffic crashes can be prevented if doctors give roadside emergency treatment to victims at the scene of the crash. The provision of excellent medical treatment at roadside crashes needs special training and experience for a medical doctor to provide advanced medical care. These crash scene roadside treatment aim to promote oxygenation and preserve clot, with rapid movement of victims to the hospital with the appropriate facilities to provide definitive care (Coats and Davies, 2002). Coats and Davies stressed the need for the crash scene to be made safe and the safety of emergency service workers at the scene as a priority.

B. *The Enhancement of Road Safety from Engineering Perspective*

Engineers have a very important and paramount role to ensuring high degree of safety on roads. From an engineering perspective as stated by Kapila *et al.,* (2013), road safety can be enhanced or improved by Highway Engineers into the different stages of road projects. These stages are planning, design, construction and maintenance and operation stages. Ahmed (2013) supported that improved safety measures put in place during planning, design, construction and maintenance and operations of roads can raise the quality of road networks and improve road safety that will benefit all road users.

1) *Planning stage*

Kapila *et al.,* (2013) believe that road safety can be enhanced through land use control policies; the provision of by-passes for congested towns and linking the by-passes by spurs; and the avoidance of nonessential traffic in the neighbourhood by the creation of Self-Contained zones.

Stakeholders involve in the planning should use a safe system approach to put in place safe system that reinforces the road safety strategy. They should plan to build road systems where accidents and injuries are not acceptable, and errors caused by drivers should not result to serious injuries. Strong road safety management systems should be put in place where its integration with other elements such as vehicles and vehicle speeds, road and roadside infrastructure and the respect of the law by road users can help to improve road safety (Smart and Arnold, 2008).

Road Safety Audits should be carried to determine the project crash potential and the safety performance. It should equally identify shortcomings in the safety of the road and put in place an action plan to correct the shortcomings.

A road Safety Impact Statement should be done to assess both the positive and negative impact on road safety on the project and it should be incorporated into the road development programme. Specific road safety objectives should be set at the planning stage of the project.

2) Design Stage

Kapila *et al*., (2013) advocates that the most desirable design standards should be selected to design “Self-Explaining Roads” and “Forgiving Roadside”. They discourage the use of minimum standards. These most desirable standards to be selected according to Kapila *et al*., are:

i. Design speed
ii. Horizontal and vertical geometry
iii. Cross-sectional elements
iv. Design of at-grade and grade separated junctions
v. Provision of service roads for segregation of slow and fast traffic
vi. Designing effective road furniture, vis-à-vis guard rails, traffic signage, roadside illumination provisions, etc.

As part of the safety measures in design of highways, Lamm *et al.,* (1991) recommend that traffic safety should be enhanced in the design of highways by increasing friction supply wherever it is possible to do so.

Lamm *et al*., carried out a comparative analysis of side friction demand versus side friction assumed to explore whether the existing policy on geometric design of highways and streets put in place by the American Association of State Highway and Transportation Officials (AASHTO) provides suitable safety measures of driving for new designs, redesigns, and rehabilitation strategies at curved site. Geometric design, operating speed, and accident data for 197 curved roadway sections in New York State were used by Lamm *et al*., as the basis of their study. They used degree of curve, operating speed, and accident rate as their independent variables. With respect to the degree of curve, their research revealed the followings:

i. Friction increases with an increase in the degree of curve
ii. With curves less than or equal to 6.5 degrees, the side friction demand is less than the side friction assumed.
iii. For curves which are greater than 6.5 degrees, side friction assumed is lower than side friction demand
iv. As the degree of curve increases, the gap between friction assumed and friction demand also increases.

Regarding the operating speed, their study revealed that:

i. Friction decreases with an increase in operating speed
ii. With an operating speed of 50 mph, side friction demand is greater than side friction assumed
iii. As the operating speeds decreases, the gap between side friction assumed and demand increases.
iv. When operating speed is greater than 50 mph, side friction assumed is usually greater than side friction assumed

With respect to the accident rate, the study revealed that:

i. When the accident rate is six or seven accidents per million vehicle-miles, side friction demand start exceeding side friction assumed
ii. An increase in accident rate leads to gap increase between side friction assumed and side friction demand.

General analysis indicated that, in the lower design speed classes combined with a maximum allowable degree of curve classes, it is possible that,

i. Friction demand is greater than friction assumed
ii. There is a higher risk of accident because there is an existing danger of an imbalance between design speeds and operating speeds at lower design speed levels.

From the above, Lamm *et al.*, observed that driving dynamic safety impacts the geometric design, operating speed, and accident rate on curved roadway sections of two-lane rural highways. With regards to their observation, they concluded that the overall safety improvement that can lead to a better harmony between friction assumed, and friction demand can only be achieve by interaction among the following three geometric criteria:

i. By achieving consistency in horizontal alignment
ii. By balancing design speed and operating speed
iii. By providing adequate dynamic safety of driving.

Though earlier research by Lamm and Choueiri (1987) reveals that the issue of adequate dynamic safety of driving is just one aspect of safety in modern geometric highway design, Lamm *et al.,* summarily concluded that when improving traffic safety, the three issues related to safety should strongly be considered by state agencies when carrying out new designs, redesigns and rehabilitation strategies as a neglect of any one of the three related issues will only lead to the achievement of partial results.

Kapila *et al.*, 2013 summarised the key elements of Safe Road Infrastructure Design as can be seen in the appendix below.

3) Construction stage

During the construction process, safety measures such as adequate separation of the construction zone using barricades; construction of good traffic diversions; providing road signage; the reduction of noise and dust through environmental control measures, etc. are proper safety measures to put in place during the construction phase of the project.

According to Kuruvilla and Saud (2017), advance actions should be taken to finalise the alignment of any highway development and ensure that there is no infringement on the right of way. They further recommended the application of modern construction procedures to attain eco-friendly and fast construction of the highway project. Modern machineries should be used for the construction of pavement as they increase construction quality and lifespan of the road. Kuruvilla and Saud (2017) further advocated for the implementation of strict quality control measures during construction to ensure design norms and technical specifications are fully respected and implemented by the contractor during construction and the contractor should take responsibility for the construction quality over the service period of the road.

4) Maintenance and operation stage

Regular maintenance should be carried on the road to improve traffic flow and safety in a cost-efficient manner and save operating cost of vehicle.

Provision of Automated Traffic Management System (ATMS) for the operation of Traffic and Incident Management in a safe manner are encouraged. This includes the provision of Variable Message Signs, Weigh-in-Motion System, Mobile Communication Systems and Central Control Room. This will help to locate alignment inconsistencies and cause abrupt changes in operating speed. This kind of mechanism would permit the engineering agency to provide cost-effective horizontal alignment modifications consistent with the resurfacing, restoration, and rehabilitation (RRR) program, thus enhance traffic safety on two-lane, rural highways (Lamm *et al*., 1988). An objective method of identifying hazardous elements that require abrupt operating speed changes would enable the agency to make geometric revisions while other deficiencies are being remedied.

Kuruvilla and Saud (2017) encourage governments to encourage the use of latest IT and GIS based technology in traffic management, fleet management, trip scheduling, traffic enforcement and road safety.

III. Conclusion

When developing strategies and policies and designing safe roads to eliminate accidents and injuries, stakeholders involve needs to use a safe system approach to road safety as that strengthen national road safety strategy that helps in the promotion of the construction of road system that help to eliminate or limit the number of fatal injuries resulting from crashes.

The making of safe highways or roads is a shared responsibility between the designers/operators of the road system and the road users. The integration of elements such as roadside infrastructures, vehicle speed, road, vehicle, and respect of the law by road users can form a safe system. A sustained improvement in road safety can be delivered through the safe system and the support of road safety management systems that are strong. Systems that support management and reflect the new approach to road safety should be developed.

Road construction projects should be designed and built to reduce the number of severe crashes and to improve the effects of crashes.

During the planning and designing of traffic facilities, pedestrians must be regarded as a traffic unit since they are vulnerable road users. During the formulation of the highway scheme, the development plan should give priority to pedestrians' safety.

The design norms and technical specifications must be respected during construction to ensure good quality and safer roads.

The issue of road safety should not only be an issue to be dealt with only by road safety managers or law enforcement officials, but it should be seen as an issue to be dealt by everyone.

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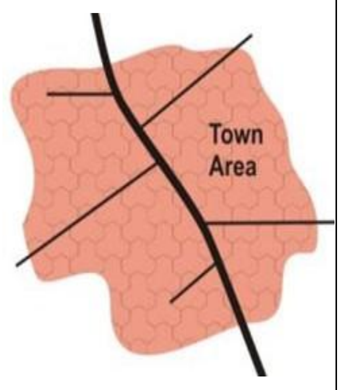
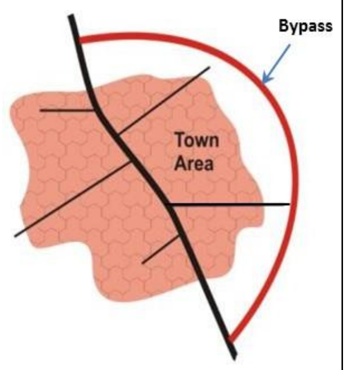
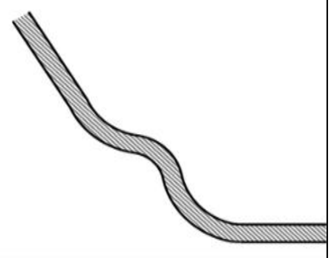
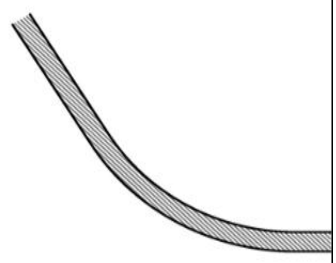
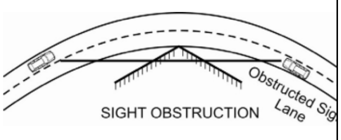
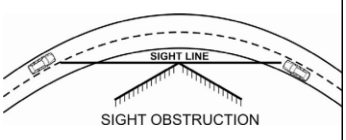
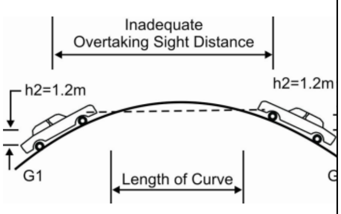
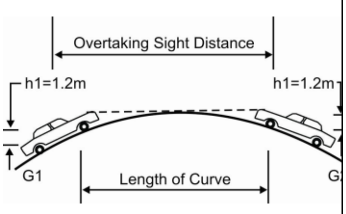
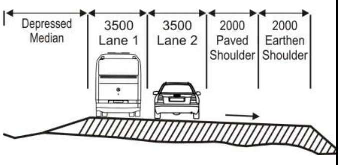
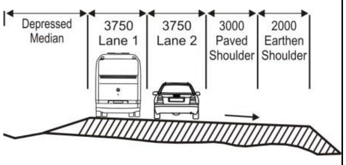
APPENDIX

TABLE 1. Key Elements of Safe Road Infrastructure Design (Adapted from Kapila *et al*., 2013)

<table>
<tr><th>Design/ Planning Element</th><th>Undesirable</th><th>Desirable</th><th>Principle applied</th></tr>
<tr><td>Alignment Selection and Land Use</td><td>
</td><td>
</td><td>Major arterials and expressways should bypass major towns which should be connected by spurs.
There should be clear zones identified for linear land use control</td></tr>
<tr><td>Horizontal Geometry</td><td></td><td></td><td>Consistency of horizontal geometry avoiding monotonous straight lines or abrupt change of speed.</td></tr>
<tr><td>Horizontal Geometry</td><td>
</td><td>
</td><td>Adequate off-set distance from natural road side features.</td></tr>
<tr><td>Vertical Geometry</td><td>
</td><td>
</td><td>Undivided Carriageways designed for desirable Overtaking Sight Distance (OSD)</td></tr>
<tr><td>Cross-sectional Elements</td><td>
</td><td>
</td><td>Wider lane widths and shoulders for high speed roads</td></tr>
</table>

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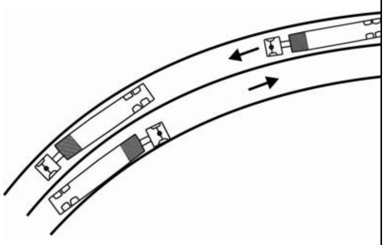
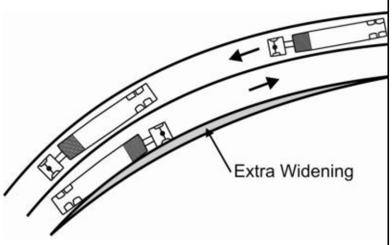
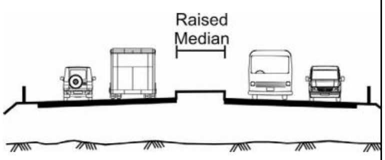
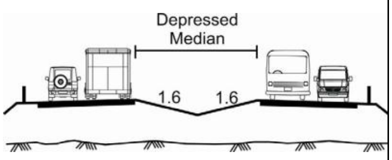
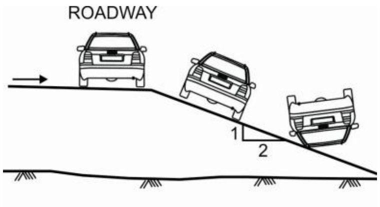
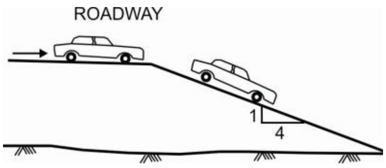
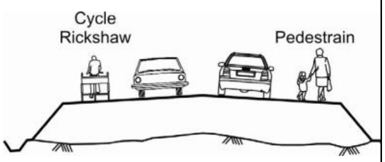
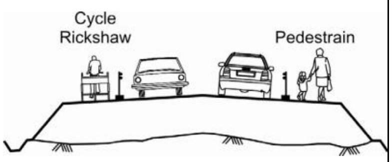
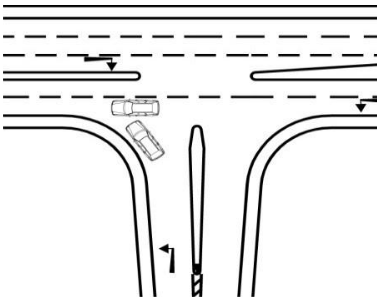
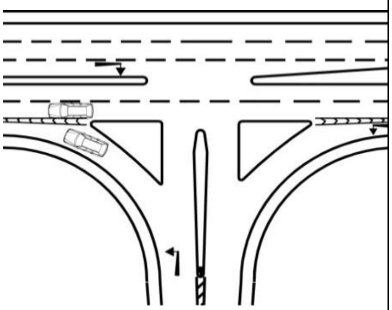
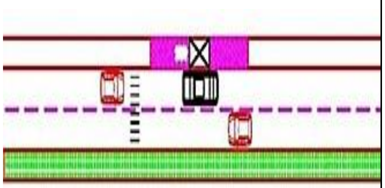
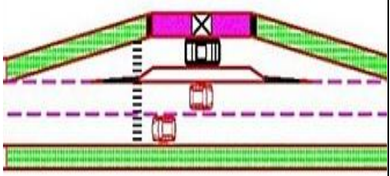
<table>
<tr><th>Design/ Planning Element</th><th>Undesirable</th><th>Desirable</th><th>Principle applied</th></tr>
<tr><td>Cross-sectional Elements</td><td></td><td>
</td><td>Inside widening for sharp curves</td></tr>
<tr><td>Cross-sectional Elements</td><td>
</td><td>
</td><td>Wider depressed median for high speed roads to prevent glare and jumping of vehicles</td></tr>
<tr><td>Cross-sectional Elements</td><td>
</td><td>
</td><td>Recoverable slopes for out of control vehicles</td></tr>
<tr><td>Cross-sectional Elements</td><td>
</td><td>
</td><td>Separate slow moving non – motorized traffic (cycles, rickshaws, etc.) from fast moving traffic</td></tr>
<tr><td>Entry/ Exit</td><td></td><td></td><td>Entry Exit only through slip lanes with proper acceleration and deceleration lanes</td></tr>
<tr><td>Passenger Transit</td><td></td><td></td><td>Separate Lay bye for buses and taxis to facilitate segregation and improve visibility</td></tr>
</table>

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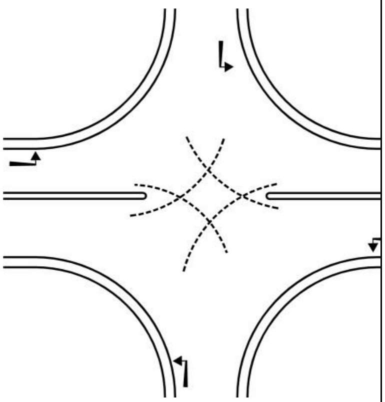
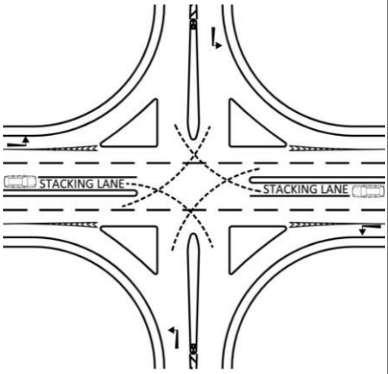
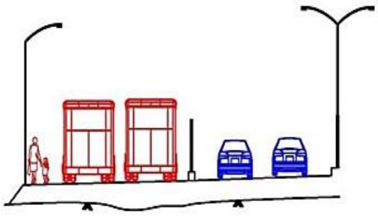
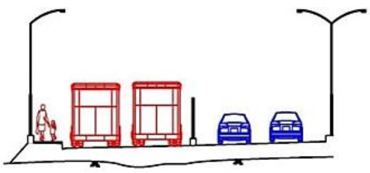
Design/ Planning Element	Undesirable	Desirable	Principle applied
Junction Design			Channelization, provision of stacking lanes, adequate turning radii
Pedestrian Facilities in Urban Areas			Provision of raised footpath for pedestrians in Urban Areas
Facilities for differently abled			Footpath merging in a slope with a cross street, bus bays flushed with foot boards etc.
Barriers			Barriers should be designed to deflect the vehicle and not crash it.
Road Signs			The road signs should be standardized throughout the country

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Design/ Planning Element	Undesirable	Desirable	Principle applied
Traffic Calming	 *Non-standard Hump*	 *Standard Hump*	Properly designed traffic calming devices like speed humps, rumble strips, small roundabouts