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Status of Safety and Security Issues in Indian Road Transport Sector and Roadmap

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ABSTRACT

Road traffic crashes are one of the world's largest public health and safety threats. This is a more serious issue in developing countries like India, which has one of the densest road networks in the world. Road collisions involve extreme human suffering and monetary costs such as premature deaths, injuries, and loss of potential income. The main objective of this study is to present a detailed analysis of road collisions and various factors affecting the fatality of these collisions on Indian roads. This is achieved by in-depth data analysis to correlate the number of road collisions and deaths in these road collisions with different factors responsible such as the type of vehicles, causes of road collisions, age of road collision victims, road environment, vehicle density of roads, transport infrastructure, etc. This article shows that most road collisions occur due to human errors, which can be avoided by implementing stricter road safety norms. Vehicle safety measures and road infrastructure also play an important role in a road collision. The road quality in India is inconsistent due to a lack of standardization and inadequate maintenance protocols. Serious research and management efforts are required in traffic management, vehicle design, and passenger safety in the Indian transport ecosystem to avoid these problems. A comparison of safety aspects of Indian roads with other developed countries is an important section of this study, which presents many important facts and issues of the Indian road transport sector. Overall, this review article provides detailed information about the safety aspects of the Indian road transport sector and a roadmap for improving this grim situation.

1. Introduction

Safety in the road transport sector is an important area for research because traffic safety improvement is critical for the road transport sector. In recent years, safety issues of the road transport sector have become more serious and require more scientific attention. Standard measures used in assessing road safety interventions are fatalities and killed or seriously injured (KSI) rates per billion (10^9) passenger-km. The World Health Organization (WHO) reported that fatalities in the road transport sector are the eighth leading cause of death worldwide and the second leading cause of disability in developing countries by 2020 (WHO, 2018). In a recent report, WHO reported that road collisions resulted in the highest number of deaths of children of age group 5-14 years and adults of age group 14-30 years (WHO, 2013; WHO, 2018). It has been forecasted that road collisions will continue to increase worldwide, imposing an increasingly greater burden on society. It has been already predicted that deaths from road crashes globally could rise to 1.9 million per annum in 2020, which has been already reached ~1.5 million in 2018 (MoRTH, 2018; WHO, 2018). Statistics show that > 50 million people are injured in traffic collisions on the roads, including minor to major injuries (MoRTH, 2018; Babu et al., 2016). Road collisions and deaths affect not only personals, but the country's economy also gets affected significantly. The cost of treatment involved with the injured persons and the loss of productivity of persons, who died or were physically disabled in road collisions are two main factors that affect a nation's economy. Among different countries, the economies of developing countries like India and China, with massive populations, have been significantly affected by road collisions (WHO, 2018; Wang et al., 2019). According to the WHO report (2013), simple prevention measures could halve the number of deaths, including enforcement of safety devices like airbags, seatbelts, helmets, and awareness against drunk driving. According to Ministry of Road Transport and Highways (MoRTH) report (2018), India has the maximum number of road fatalities globally, continuously increasing year-on-year (YoY). The rise in the number of road collisions is impacted by many factors such as increasing population, growing urbanization, migration, increasing length of the road network, increasing vehicle population, and lack of adherence/ enforcement of road safety rules (MoRTH, 2018). Road traffic safety refers to methods and measures undertaken for reducing the risk of a road user being killed or seriously injured. India has mixed road traffic on its roads, where the pedestrians, cyclists, cars, trucks, buses, etc., share the same road space, and each of these categories of motorized and non-motorized vehicles have their own speed. Road collision-related injuries are highly dependent on the speed of the motor vehicle since, with an average increase in vehicle speed of 1 km/h, there is a 3% higher risk of a crash involving an injury (Singh, 2017). Hence, there is a need to segregate fast-moving and slow-moving vehicles and enforce the speed limits on the fast-moving vehicles.

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Fig. 1 shows the global safety trends in terms of the total number of collisions, number of persons injured, and number of persons killed in road collisions. In fig.1, it is clearly shown that the USA has the maximum number of road collisions, followed by Japan and India. A relatively higher ratio of the number of persons injured in road collisions w.r.t. the total number of road collisions in the USA exhibit the severity of collisions. In comparing the USA, other counties, especially India and China, have fewer road collisions; however, the number of deaths involved in road collisions compared to a total number of road collisions shows a relatively higher fatality rate than the USA. According to the WHO report (2019), India has roughly four times the number of accidental deaths than the USA (37461 and 150785 respectively). These numbers are even more appalling for every million motor vehicles, indicating 13.4 deaths in India against 1.5 in the USA.

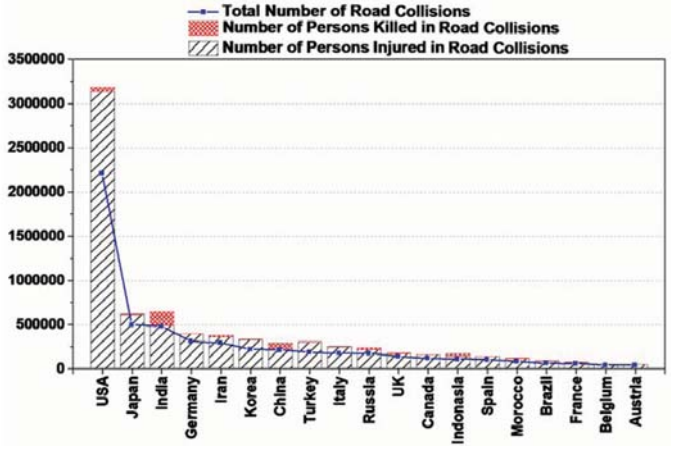

Fig. 1 Global road transport status in terms of the total number of collisions, number of persons injured, and number of persons killed in road collisions in 2018 (WHO, 2018; MoRTH, 2018)

Fig.2 shows that India and China havea significantly lower road collision and the number of injured persons than other countries such as the USA, Korea, Canada, etc. Significantly higher population in these countries is the leading cause of this fact; however, the population's effect is not visible in the total number of deaths in road collisions. Data shows that India has the fourth-highest fatalities per million population (113) (WHO, 2018), increasing YoY. These numbers are already very high, and recent growth and development in the Indian road transport sector make this scenario even worse. The higher fatality rate of road collisions exhibits the failure to implement road safety measures, lack of awareness, and loopholes in the road transport management system.

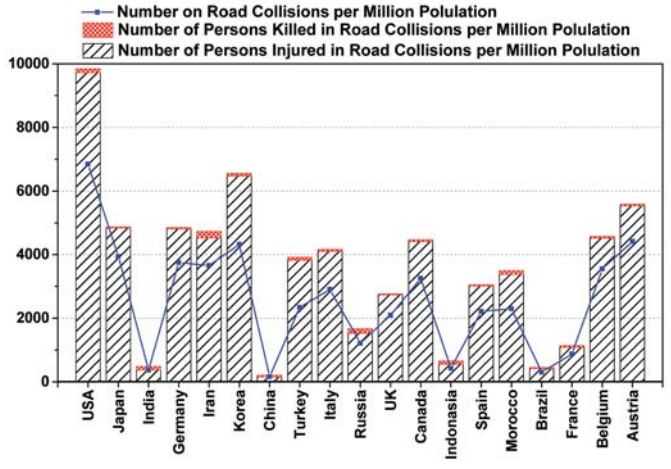

Fig. 2 Global road transport status in terms of the total number of collisions per million population, number of persons injured per million population, and number of persons killed per million population in road collisions in 2018 (WHO, 2018; MoRTH, 2018)

In another report, the global safety trend is presented in the number of fatalities per million vehicles, which exhibited that India has the maximum number of fatalities per million vehicles (2118). Therefore, it is the right time to cut these fatalities by making the Indian road transport sector safer, similar to other developed countries such as UK, Germany, Australia, etc. Developed countries have adopted an ambitious 'Road Safety Program' to cut road deaths severely by 2020. European (EU) roads are considered the safest, with 49 road fatalities per one million inhabitants (European Commission - Fact Sheet, 2018). Between 2001 and 2010, the EUcut the number of road deaths by 43% and between 2010 and 2015 by 17%. 26,112 people lost their lives in the EU in 2016, which was 5,400 fewer than in 2010. EU has set a target of <20000 road fatalities by 2020, which they have partially achieved and cut down the number of deaths to ~25000 in 2017. This decreasing trend of fatalities is attributed to the enforcement of safety measures on the field, awareness among drivers, and strict penalties for violators. The EU program sets out a mix of initiatives at the pan-European and national level, focusing on improving vehicle safety, safety infrastructure, and road users' behavior. Initiatives proposed in the "European Road Safety Policy Orientations" range from setting higher standards for vehicle safety, improving the training of road users, and increasing the enforcement of road usage rules. Some of the safety features used areLimited access from properties and local roads to the highways, and grade-separated junctions, Median dividers between opposite-direction traffic to reduce the likelihood of head-on collisions, to remove roadside obstacles, Prohibition of more vulnerable road users, and slower vehicles, Placements of energy attenuation devices (e.g., guard rails, wide grassy areas, sand barrels) and Eliminating road toll-booths (Castillo-Manzano et al., 2014). In addition, attention is being given to improving safety measures for vehicles, driver training, the development of intelligent roads and vehicles, and strict law enforcement. Case studies show that the severity of road collisions is also affected by the post-accidental activities and availability of medical facilities to the victims of road collisions (Másilková, 2017; Gokul et al., 2020). Statistical data depicts that in half of the road collisions, death occurs due to the unavailability of initial medical treatment before arrival at the hospital (ETSC, 1999). Therefore, it is important to consider this aspect during the expansion of the road network. WHO also emphasizes that all learner drivers should be trained in first-aid and basic life support (BLS) to provide initial treatment to life-threatening cases in such situations (Racioppi et al., 2004; Adelborg et al., 2011).

2. Indian Road Transport Safety Scenario

India has the highest number of road crash fatalities, with one crash occurring every minute and one death every four minutes (WHO, 2018; MoRTH, 2018). While it has just about 1% of the vehicles, India accounts for over 11% of global road crash fatalities – the highest in the World (WHO, 2018; Web report, 2017). In a study carried out by United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), it has been reported that the annual cost of road crashes in India is ~3% of its gross domestic product (GDP), which is equivalent to 58000 million USD (ESCAP, 2018). Statistics of road collisions in India show that India's fatality continuously increases with time (MoRTH, 2018). This is mainly due to the popularity of road transport for freight and passenger movement in India (TV2035, 2016). Fig. 3 shows that the proportion of fatal collisions in total road collisions has consistently increased since 2005, and it reached up to 33% in 2018 (MoRTH, 2018). In Fig. 3, this can be seen that road collision-related deaths and road injuries were consistently increasing up to 2010. However, road collisions, deaths, and injuries showed a stable trend between 2010 to 2015 with marginal fluctuations. In the last two years (2017 and 2018), the number of road collisions and persons injured has shown a significant reduction. However, the number of deaths in road collisions has shown a continuous increase similar to previous years (MoRTH, 2013). The total number of road collisions and deaths involved in road collisions in 2018 increased slightly (~0.5% and 2.4%, respectively) compared to 2017; however, the number of persons injured in road collisions in 2018 decreased by 0.33%.

Though the number of vehicles in India has been increased from a compound annual growth rate (CAGR) of 28% in 2007 to 43% in 2017; however, the CAGR of the number of road collisions, persons injured in road collisions, and deaths involved in road collisions have been significantly decreased in decade 2010-18. In comparison to 1970-80, CAGR of the number of road collisions, persons injured in road collisions, and deaths involved in road collisions in India during the decade of 2010-2018 has decreased from 3.0% to -0.8%, 4.5% to -1.4% and 5.2% to 1.5% respectively (MoRTH, 2018). In a report issued by the MoRTH

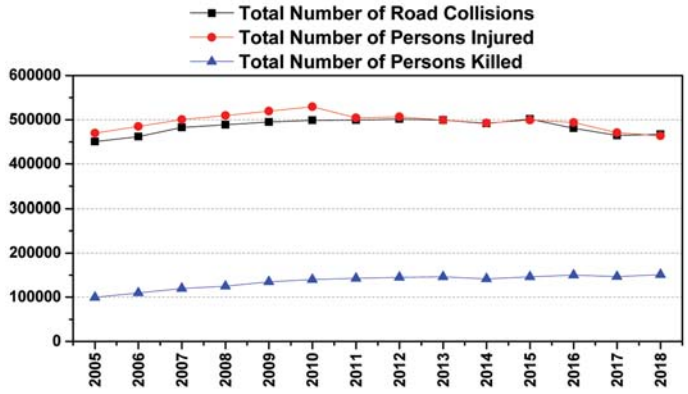

Fig. 3 Total number of road collisions, persons injured, and persons killed during 2005-2018 (MoRTH, 2018)

it has been reported that the CAGR of the number of road collisions, persons injured in road collisions, and deaths involved in road collisions were highest between 1980-1990, which reached up to 6.3%, 8.4% and 8.5% respectively (MoRTH, 2013). Fig. 4 shows other statistics related to the number of road collisions and fatalities in road collisions in India per million population. Results show an interesting trend that the total number of road collisions per million population has been decreased in the last few years; however, the total number of deaths involved in road collisions per million population remained almost constant. Fig. 4 shows that the number of road collisions per million population has increased from 212 in 1970 to 386 in 2000, followed by a sharp increase to 425 in 2010. After 2010, the number of road collisions per million population followed a decreasing trend with a minimum of ~360 in 2018.

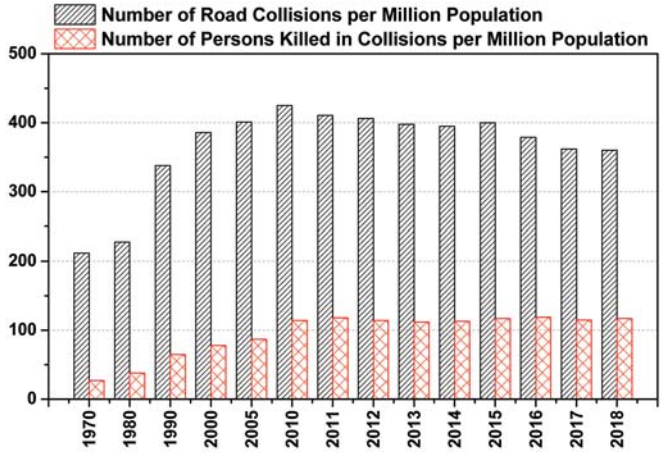

Fig. 4 Number of road collisions and deaths per million population in India between 1970 to 2018 (MoRTH, 2018; WHO, 2018)

The number of deaths in road collisions per million in India shows an interesting trend, which increased from 27 in 1970 to 117 in 2015. After 2015, the number of deaths in road collisions per million population showed an almost constant trend with ~120 deaths per million. An increase in the number of deaths per million population is more serious than the total number of collisions per million population, reducing YoY. These numbers also show the severity of collisions, increasing YoY due to the lack of awareness and casual approach such as overspeeding, mobile phones, drink, driving, etc., of road users in India.

3. Analysis of Road Collisions in India

A road collision and its severity depend on many factors, which ultimately results in either a serious collision with loss of lives or it may involve minor to major injuries to road users. Fig. 5 shows the categorization of road collisions in India in the last five years (2014 to 2018) based onthe severity of collisions and classified them into three categories: fatal collisions, collisions with significant injury, and collisions with a minor injury.

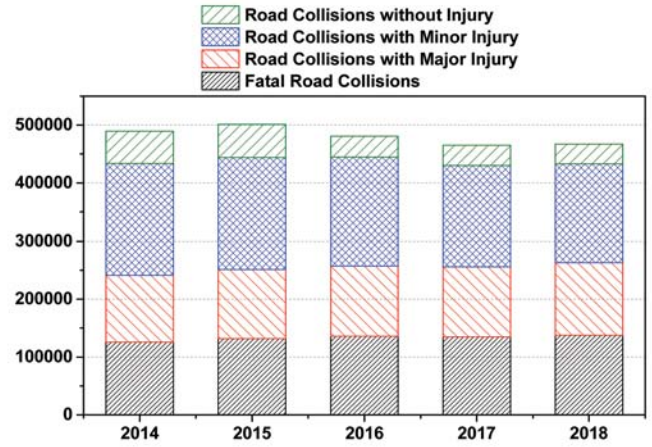

Fig. 5 Trends in the type of road collisions (2014 to 2018) (MoRTH, 2018)

The collisions, which involve the loss of life of one or more persons, are considered fatal; however, the collisions, which involved the hospitalization of one or more victims, are considered significant collisions. The collisions, which do not require the hospitalization of road collision victims, are considered minor collisions. Statistics of road collisions of the last five years show that most of the road collisions ~36% in India involve minor injuries followed by fatal collisions, which are about 30%, and collisions with significant injuries are about 27%. In India, several collisions occur each year in which no one is harmed with any injury. Such collisions are considered collisions without injury. Fig. 5 shows that the number of collisions without injury and minor injuries decreases YoY, showing the carelessness of drivers and other road users.

Similarly, collisions with significant injuries and fatalities in road collisions are continuously increasing, which is a serious issue (Dandona et al., 2019). In road collisions, the conversion rate of a collision with a major injury to fatality is another important factor. This depends on several issues in which health service availability, provision of good Samaritan laws, and free health care during the golden hour to save lives are few important ones. Good Samaritan renders aid in an emergency to an injured person, which plays an important role in most road collisions (Adusumalli et al., 2018).

The other statistical analysis presents the contribution of different age groups in road collisions. Fig. 6 shows the classification of fatalities of road collisions in 2018 based on age group, revealing that more than 55% of road collision victims were below 35 years. Fig. 6 also reveals an important conclusion that the new age group (within 25 years) contributes a significant fraction (28.2%) of total road collisions and fatalities (Copsey, 2010). This shows a lack of adequate training for the drivers, which can be improved by the parental intervention of driving lessons of young drivers. Shope et al. (2001) suggested that higher levels of parental monitoring, nurturance, and family connectedness tend to lower the rates of serious offenses, including road collisions. Bianchi and Summala (2004) suggested that children follow their parents' driving habits through genetic disposition and model learning; therefore, it's a moral duty of the parents to follow the safety rules and regulations to educate their children. Data are shown in Fig. 6 also shows another fact that older drivers (60+ year age group) also caused a significant number of collisions (~6%) compared to the 25-60 year age group (60%). Older drivers tend to have increased functional impairments, which affects their driving skills (Stefano and Macdonald, 2003).

Schlag (1993) pointed out that elderly drivers require more information before deciding, and they need more time to make decisions, leading to higher road collisions under complex situations. Therefore, driver licensing authorities need to have a valid and reliable system for evaluating older drivers' continuing competency. Many researchers (Gallo et al., 1999; Ball et al., 1998) suggested that the driving abilities of older drivers can be improved by being more selective about how, when, and where they should drive. Road collisions can be avoided by avoiding driving older people during peak traffic hours, at night, or under adverse weather conditions.

Fig.7 comparesthe total number of persons killed in road collisions in three years, i.e., 2016, 2017, and 2018. Fig. 7, the total number of deaths

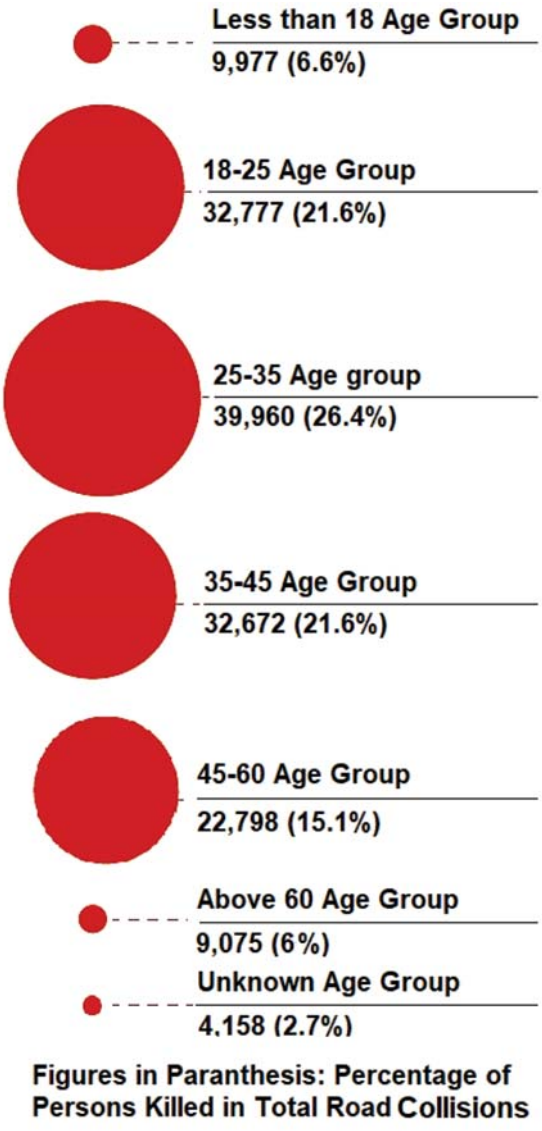

Fig. 6 Road collision victims by age group in India (2018) (MoRTH, 2018; TV 2035, 2016)

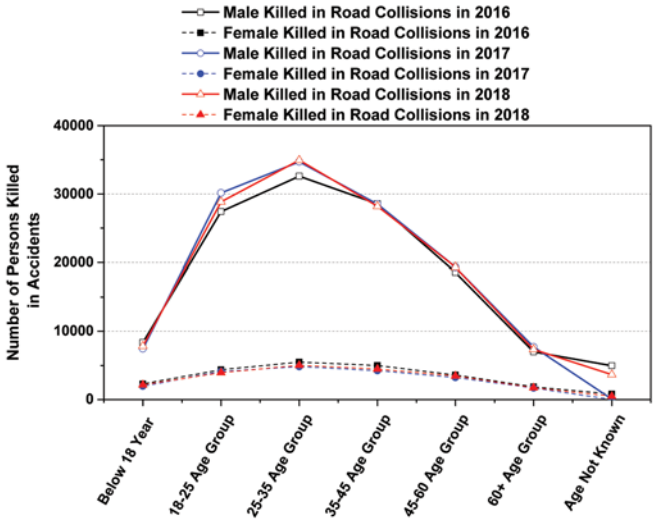

Fig. 7 Road collision victims (gender-wise) by age group in India (2016, 2017 and 2018) (MoRTH, 2018)

has been divided into two categories on a gender basis. Fig. 7 shows that the numbers of male victims of road collisions in all three years are significantly higher than females. In Indian road transport sectors, the dominance of male drivers might be the possible reason for this trend, which is even more dominant in relatively young age groups (18-45 years).

Similar to fig. 6, fig. 7 also reveals that younger people (both male and female) are more involved in road collisions than older people. This trend has remained the same in all three years, i.e., 2016, 2017, and 2018, which exhibits the implications on the economic cost of road collisions and their emotional and psychological impact. Like 2016 and 2017, young adults (18-45 age group) were involved in ~70% of road collisions; however, the working-age group (18-60 years) accounted for even more, which reached ~85% in 2018. Comparison of peaks of the graphs reveals another important aspect that females victims of different age groups involved in road collisions are more uniformly distributed than male victims. Continuously increasing deaths of young male age group in three consecutive years show another important issue related to road collisions, which needs serious attention. In 2018, the death of male victims of age group 25 to 35 had reached up to ~35000, which was ~32000 in 2016. In 2018, the number of female victims of road collisions showed a slight reduction compared to previous years.

Fig. 8 shows fatalities due to collisions involving various types of vehicles in 2018. The vulnerability of the roadusers to collisions is high as the same road space is being shared among a wide variety of motorized, non-motorized vehicles and pedestrians.

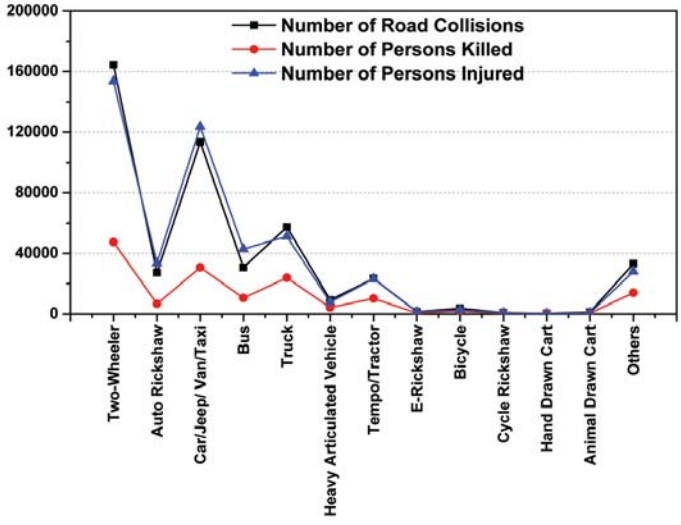

Fig. 8 Number of road collisions, persons killed and persons injured in various vehicle categories in India in 2018 (MoRTH, 2018)

From fig. 8, it is clear that the percentage share of collisions by two-wheelers, cars, and trucks is relatively more than other modes of transport put together. This is attributed partly to an increase in the number of vehicles on the roads. Compared to two- and three-wheelers, the superior construction of four-wheelers and heavy-duty vehicles also offers inherent protection in collisions and reduces respective fatalities. A significant contribution of two-wheelers on roads compared to cars is another important reason for relatively higher fatalities from two-wheelers (33.8%) than cars (23.6%). Hence there is a need to focus on safety-related interventions in this segment. In the last few years, a large number of many rules and regulations such as mandatory helmet wearing, increased penalties for traffic rule violations, etc., have been imposed in the Amended Motor Vehicle Act passed by the Parliament in 2019. Fig. 8 shows that the number of accidents and the number of persons injured due to bus accidents is also very high. This is mainly due to the use of buses in public transport, where many passengers are affected during accidents. Therefore, it is necessary to use advanced safety techniques in buses to reduce these numbers (Li et al., 2020).

Fig. 9 shows the trend in the number of collisions per ten thousand km of road length and ten thousand vehicles over the last few decades.

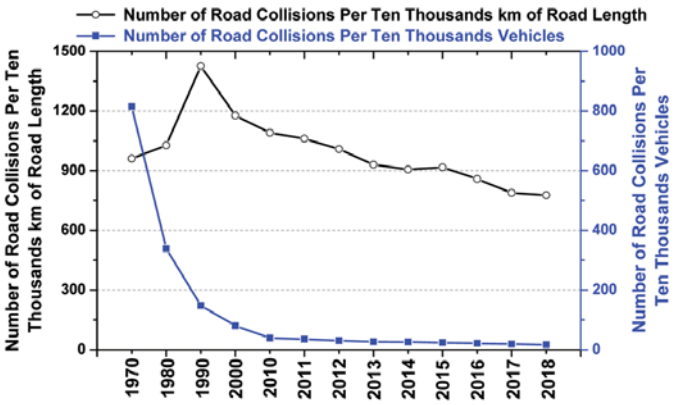

Fig. 9 Number of road collisions per ten thousand-km of road length in India between 1970 and 2013 (MoRTH, 2018)

A noticeable expansion in vehicular transport in India, particularly for goods vehicles, was observed between the 1940s to 1960s. The number of goods vehicles in undivided India (excluding princely states) increased from 12,397 in 1938-39 to ~160,000 in 1960-61. This growth generated the need foreffective traffic planning to control and regulate these vehicles plying across the length and width of the country. In the 1960s, according to the calculations presented in the Preliminary Report of the 'Committee on Transport Policy and Coordination, the increase in freight traffic by road was expected roughly to be of the order of ~120% over five years, i.e., from 10,600 million ton-miles in 1960-61 to 23,350 million ton-miles in 1965-66. At the end of 1968, a tremendous variation was found in vehicular traffic in both sectors, i.e., freight and passenger transport sector. The passenger traffic increased from 98,000 million passenger-km in 1968-69 to ~140,000 million passenger-km in 1973-74. In order to cater to this estimated increase in traffic, the number of trucks on the roads increased from ~300,000 in 1968-69 to ~470,000 at the end of 1973-74, and the number of buses increased from 85,000 to 115,000 during the same period. The indigenous production of commercial vehicles increased from 35,000 in 1968-69 to 85,000 in the last year of the 4th five-year plan. The sestatistics highlighted a continuous growth in the number of vehicles in India historically. While the population of India has increased by 17.64% over the past ten years, the number of licensed vehicles has increased by over 132% during the same period (WHO, 2013). At the end of 2010, there were ~117 million registered vehicles in India. This number is expected to grow three-fold by 2035 (TV2035, 2016). It was challenging to handle many such vehicles on the Indian roads due to a limited increase in the road network. Thus the traffic congestion and number of road collisions increased drastically in India. Hence urgent technological interventions were required to be enforced to halt and reverse this fatality trend. Governments have already made significant efforts to control the collisions and number of deaths involved in road collisions. According to MoRTH, the number of deaths per ten thousand vehicles has decreased in recent years, reflecting improved crash-worthiness of the vehicles and better occupant protection (MoRTH, 2013; MoRTH, 2018). Fig. 9 shows that the number of collisions per ten thousand vehicles was highest in 1970 (~1200), which decreased significantly to ~25 in recent years. However, other statistics show that the number of collisions per ten thousand km was 960 in 1970, which rose to 1,027 in 1980 and peaked at1,425 in 1990. After that, it showed a continuous declining trend going up to ~800 collisions per ten thousand km in 2018 (MoRTH, 2018). The number of collisions per ten thousand km of road length was significantly higher in 1990 due to higher risk exposure because of heterogeneous traffic (different categories of vehicles including two-wheelers, three-wheelers, passenger vehicles, commercial vehicles, etc.), lack of traffic separation, etc., which has been significantly improved in next few decades.

According to the Ministry of Safety and Highways, road collisions were the 9th leading cause of death in India in 2004. Road collisions are expected to be the 8th leading cause of death by 2030 worldwide. This requires serious thoughts and introspection for the development of effective traffic planning and safety systems. Road collisions are multi-causal and result from an interplay of various factors in which human error, road condition, environment, etc., are important. In more than 90% of road collisions, human error is an important element and often is the sole cause of collision (Fig. 10) (Bucsuházy et al., 2020). Road collisions caused by human error include (i) cases of collisions caused by traffic rule violations, (ii) driving without a valid driver's license, and (iii) non-use of safety devices. This sub-section of the article describes the causes of road collisions and involvements of different segments of road users in road collisions.

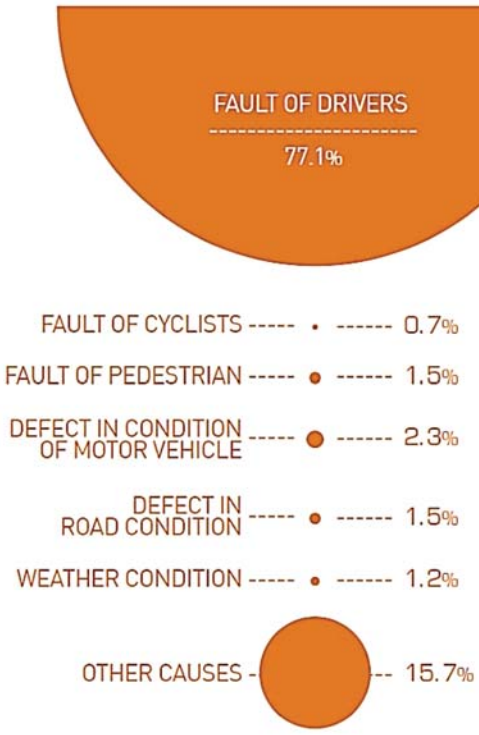

Fig. 10 Main causes of road collisions in India (MoRTH, 2018; TV2035, 2016)

Fig. 10 shows a general classification of different road users who are involved in road collisions. Analysis shows that the driver's fault is the main cause of most road collisions. In most collision rules, the driver's violation results in acollision, which sometimes becomes life-threatening. In some road collisions, especially in India, the driver's fault leads to the injury/death of the driver. However, other road users such as pedestrians, cyclists, etc., are injured/died in road collisions. Fig. 10 also shows several causes of road collisions, such as poor road condition, issues with the vehicle, poor weather condition, etc., which have been discussed in more detail in the next sections. Among different causes of road accidents, road conditions such as poor roads, sharp turns, unavailability of road signs, absence of road light, etc., are important. These issues can be resolved by adopting advanced road designs and by regular maintenance of roads. Fig. 11 shows different types of road collisions, which are mainly caused due to the fault of the driver.

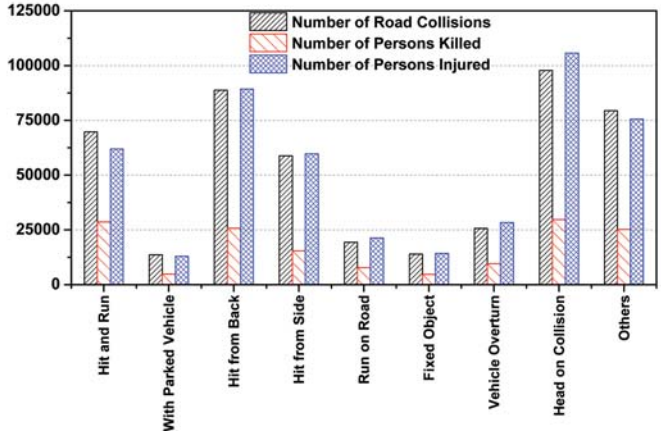

Fig. 11 Types of road collisions in India in 2018 (MoRTH, 2018)

Fig. 11 shows that most of the collisions and injuries on Indian roads are caused due to vehicle-to-vehicle collision, which might be either a head-on collision or a hit from the back. In this type of collision, mostly the drivers get affected due to the direct impact of vehicles. Fig.11 reveals that head-on collision, hit and run and hit from the back accounted for ~56% of persons killed in road collisions in 2018. In many cases, it has been observed that collisions due to vehicle-to-vehicle collision lead to the death of the driver; however, passengers are injured with minor to major injuries. A relatively higher number of injuries and deaths in a head-on collision thana hit from the back also exhibit the severity of such collisions. The hitting of vehicles from the side is the third cause of road collisions. Fatality is relatively lower than head-on and hit from back collisions; however, the number of injuries is almost similar to the number of collisions. In India, hit and run also contributes to many collisions, injuries, and deaths. Lack of proper vigilance and surveillance might be the prime reason for significantly higher hit and run cases in India. However, nowadays, many efforts have been made to reduce the cases of hit and run on Indian roads. There are several other causes of road collisions, such as collision with a parked vehicle, fixed object, vehicle overturn, etc. The fatality rate of vehicle overturns relatively higher than other causes.

Fig. 12 shows the comparison of road collisions caused by driver's faults such as over-speeding, driving under the influence of alcohol or drugs, lane indiscipline, jumping a red light, unsafe overtaking maneuvers, etc., two consecutive years, i.e., 2017 and 2018.

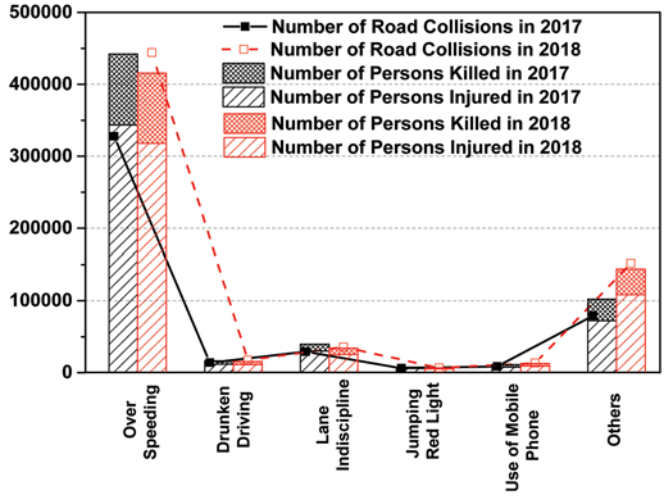

Fig. 12 Number of road collisions, persons injured, and persons killed in 2017 and 2018 due to traffic rule violations (MoRTH, 2018)

Fig.12 reveals that over-speeding is the main cause associated with road collisions, which accounted for ~65% of the total number of road collisions, ~64% of the total number of deaths in road collisions,and ~68% of the total number of persons injured in road collisions. Different control techniques, including vehicle speed control instruments, stricter rules for speed control, etc., have been implemented for the road transport sector (Aljanahi et al., 1999). The comparison of 2017 and 2018 shows that the number of collisions due to overspeeding were increased in 2018; however, the number of persons injured in these collisions has been slightly reduced. Road collisions due to overspeeding can be reduced by improving the information available to the road user about the existing speed limits and warning them immediately and swiftly when these limits are exceeded. Many countries have adopted this technique, and positive results have been observed (Borsati et al., 2019). Driving on the wrong side/ lane indiscipline is the second most important cause of road collisions in both years; however, the number of road collisions due to lane indiscipline in 2018 is relatively lower thanin 2017.

Shang et al. (2020) suggested a two-lane traffic flow model based on the standard hexagonal cells method for reducing the number of road accidents due to lane indiscipline. Like over-speeding, the number of injuries and deaths due to lane indiscipline in 2018 is relatively lower than in 2017. In 2018, drunken driving/ consumption of alcohol & drug, jumping of red light, and use of mobile phones caused ~7% of the total number of road collisions and ~6% of total deaths in road collisions in 2018. Chaudhary and Velaga (2017) reported different aspects of mobile use during driving, leading to severe road collisions, especially highways. The other category, which may include poor road environment, faulty vehicular conditions, etc., accounted for ~25% of the total number of road collisions and collision-related injuries and deaths. These statistics show an important aspect of reducing the number of road collisions, number of persons injured, number of deaths due to overspeeding, drunken driving, lane indiscipline, jumping a red light, etc., better enforcement of traffic rules and regulation in India. However, collisions, collision-related deaths, and injuries on account of mobile phones and other causes registered an increase in 2018 compared to 2017 and needs to be focused upon for overall improvement in road safety. Previous studies have also shown that traffic rule violations are a significant cause of road collisions. Sze et al. (2011) suggested different methods for reducing red-light violations, among which strict financial penalty, driving license revocation, and suspension are the most important. Kima et al. (2011) suggested that driving license suspension should be implemented for serious faults (fatal road collisions), and license revocation should be implemented for traffic violations. On top of this, the consequences of collisions are aggravated because many drivers/ co-passengers do not wear personal safety devices such as seat belts or helmets (Bendak, 2005; Grimm and Treibic, 2016; Swaroop et al., 2014). Accurate, reliable, and timely information on traffic queues and other dangerous situations (safety-related traffic messages and alerts on incidents, collisions, extreme weather conditions) should be made available by the authorities to the drivers. Improved navigation information and better route guidance at complex intersections in unfamiliar places reduce driver stress and contribute to safer driving conditions. Technological interventions such as driver-assist and collision avoidance systems should further improve this situation. There should be aware that commercial vehicle drivers (which are often slower than traffic) must allow other drivers in passenger vehicles to pass to avoid risky overtaking maneuvers. Better information for the truck drivers on existing traffic constraints also leads to lower collisions and collisions involving trucks. Information to the driver should always be given safely, avoiding any information overload or misuse of information systems. It is important to have a comprehensive plan to achieve these objectivesto make Indian roads safer.

Fig. 13 shows the statistical data of the total number of road collisions, persons injured and killed in road collisions on different Indian roads. This data reveals that the number of collisions on national highways and state highways lower than on local roads. Relatively more local roads than national and state highways and improper safety measures and less effective rescue plans are the important reasons for this trend. On local roads, people do not follow the traffic instruction, which is another reason for the high number of road collisions. Comparison of fatality rate shows that collisions on highways are relatively more fatal compared to local roads. In 2018, the fatality rate of road collisions on state highways and national highways was~39% and ~34%, respectively; however, the fatality rate of collisions on local roads was ~26%. This shows the intensity of road collisions, which was significantly lower on local roads compared to highways. Significantly higher vehicle density and more vehicle density on highways might be the possible reason for the relatively higher fatality of collisions on highways (Gitelman et al., 2017; Liu et al., 2020).

Comparing the total number of road collisions, persons injured in road collisions, and casualties in road collisions w.r.t. unit length of different roads reveals that state is fatal than local roads. Analysis shows that national highways comprising ~1.94% of the total road network in India contributed ~30% of total road collisions, which resulted in ~35% of total deaths in road collisions in 2018. A similar analysis showed that state highways comprised~3% of the total road length in India and resulted in ~25% and ~26% of the total number of road collisions and total deaths, respectively. This data is even more disturbing for local roads, which comprises ~95% of total road length in India and resultsin ~45% of the total number of road collisions with 38% of total casualties of road collisions in 2018. Critical analysis of road collisions shows that highways (both national and state), which accounted for only ~5% of the total road network, contributed a significantly larger share of collisions (~55%) and collision-related casualties (~65%)in 2018. This is an eye-opening finding and should be taken care of immediately.

Fig. 14 shows the comparison of accidental data on different types of roads in the last five years. Fig. 14 shows that the number of road collisions in 2018 was reduced compared to 2014, in which reductions in the number of road collisions on state highways and other roads, including local roads, were more dominant compared to national highways.

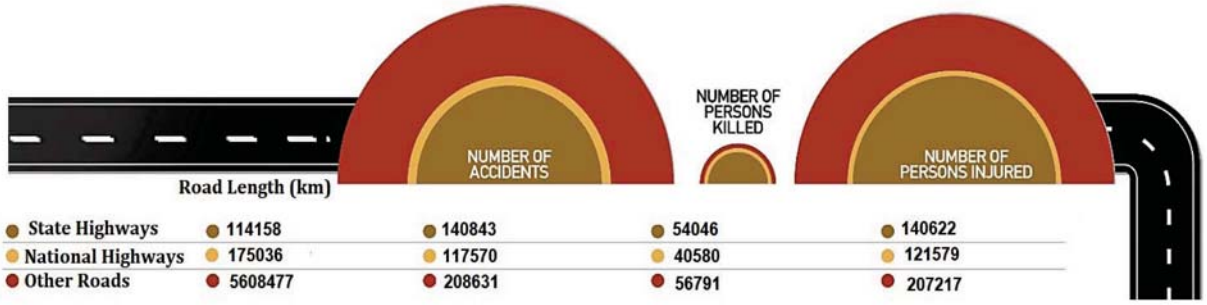

Fig. 13 Road length, number of accidents, persons killed and injured in India in 2018 as per road classification (MoRTH, 2018; TV2035, 2016)

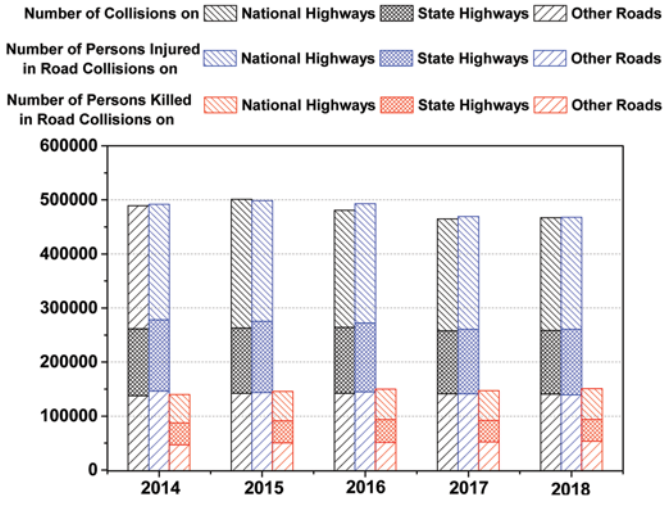

Fig.14 Comparison of the number of collisions, persons killed and injured in India in five years (2014-2018) as per road classification (MoRTH, 2018)

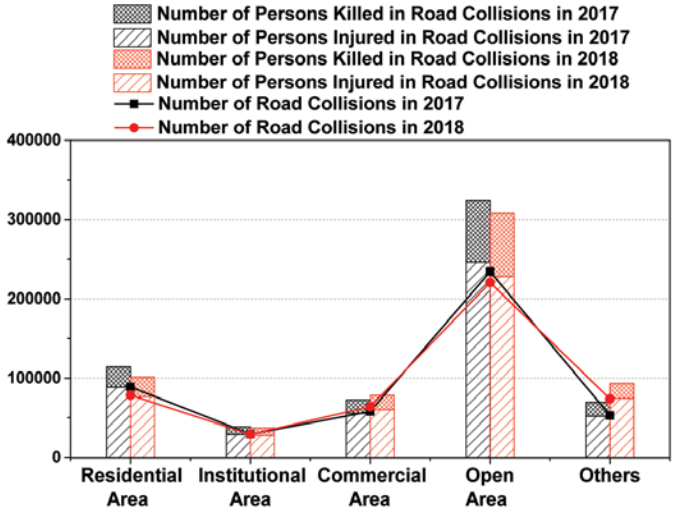

Fig. 15 Number of road collisions, persons injured, and persons killed in road collisions in different geographical areas in 2017 and 2018(MoRTH, 2018)

The number of collisions on state highways has remained almost constant in the last five years.Contrary to the number of road collisions, the number of persons injured in road collisions on local roads and national highways increases. The number of fatalities on different roads shows that the casualties in road collisions on national highways have increased since 2014, and numbers are continuously increasing. The increase in fatalities on national highways is relatively faster thanon state highways and local roads. This needs to be taken care of by applying more restrictions on vehicle speed, improving the driving conditions on national highways and implementing advanced road structures and designs (Wu et al., 2020), which has been discussed in the following sub-section of the article.

The following sub-section of this article discusses the different causes related to the category of road environment responsible for road collisions. This category is based on the collisions happening in a particular geographical area (residential, commercial, institutional, etc.) and weather conditions responsible for road collisions.

Fig. 15 shows that the number of collisions on open areas such as highways is relatively higher compared to other areas. These collisions mainly include vehicle-to-vehicle collision. Over speeding and lane indiscipline are the most common reasons for such collisions, resulting in more injuries and casualties than collisions in other areas. Relatively more traffic rule violation of such areas might be another possible reason for a higher number of road collisions. Compared to 2017, the number of collisions, number of persons injured, and casualties in such collisions in 2018 show a slight reduction. Apart from open areas, collisions on a residential area, institutional area, and market/commercial area also contribute significantly; however, their contributions were relatively lesser than open areas. The lower share of collisions, persons killed and injured in residential, institutional, and commercial areas might be due to better enforcement of traffic rules and road safety guidelines. These collisions happen mainly due to higher traffic congestion, which enhances the chance of vehicle-to-vehicle and vehicle-to-person collision. Many countries have imposed stricter speed limits in congested areas (Ang et al., 2020). In these three categories, the residential area shows the highest number of road collisions, the number of persons injured, and the number of persons killed, followed by commercial areas. The involvement of more persons in such areas isthe main reason for this trend. Road collisions in commercial areas show ahigher rate of fatalities compared to other areas. This needs to be taken care of by limiting the entry of vehicles in such areas by giving a by-pass route, or it can also be controlled by putting stricter traffic rules and regulations. This can be observed that institutional areas have a relatively lower number of collisions than other areas. Movement in a limited time range and more vigilance of road users in such areas might be the governing factors, which should also be implemented in other areas, especially in residential areas. Comparison of road collision data of 2017 and 2018 shows that the most significant increase in collisions, killed and injured, was recorded in the commercial areas. Residential & Institutional areas recorded a decline in collisions, killed and injured in 2018.

Fig. 16 shows the number of collisions, number of persons injured, and number of persons killed in road collisions due to the different loading nature of vehicles. This loading may be for all kinds of vehicles, including two-wheelers; however, this data is mainly related to heavy-duty vehicles. Most of the heavy-duty vehicles are involved in serious collisions mainly due to tires bursting from excess weight, brakes wearing by the overloading, road collapses caused by overloaded trucks, roll-over of trucks caused by the center of gravity shifting from overloading, excess weight adding momentum to a truck traveling downhill and severely slowing it down when traveling up an incline. Analysis shows that most of the collisions occurred with typically loaded vehicles, which increased in 2018. However, the number of collisions and collision-related injuries and death from overloaded vehicles showed a slight reduction in 2018. This shows a good sign that collisions and casualties have decreased, which might be mainly due to the implementation of stricter rules and regulations.

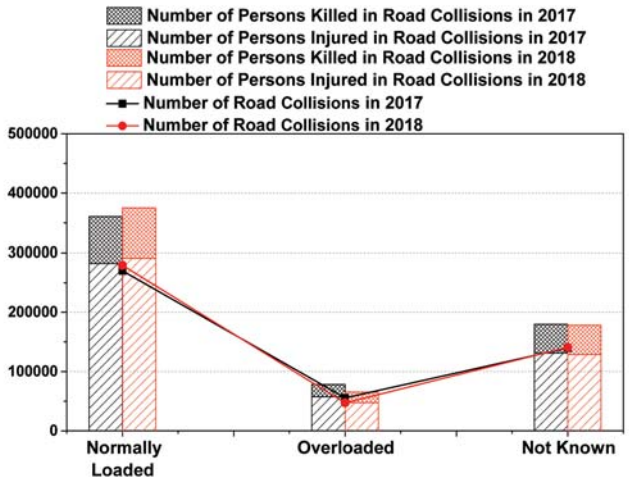

Fig. 16 Vehicle loading condition responsible for the number of road collisions, persons injured, and persons killed in road collisionsin 2017 and 2018 (MoRTH, 2018)

The shifting of the weight of the overloaded truck on its rear wheels might be another reason for road collisions, which creates difficulty in steering the vehicles. In few studies, it has been reported that partially loaded tankers (used for transportation of liquids such as fuels, milk, water, etc.) tend to lose their control due to the movement of liquids back and forth.Therefore, it is necessary to carefully examine these factors to ensure the proper loading of commercial vehicles. A few studies have reported that overloaded vehicles with loads protruding/hanging pose serious traffic hazards, risking themselves and other road users. These issues can be resolved by the implementation of guidelines on different kinds of road users. There should be a specific load limit for heavy-duty and light-duty vehicles, including two-wheelers, and these guidelines should be strictly followed. There should be a proper route of operation for different kinds of vehicles, such as entry of heavy-duty vehicles should be restricted/avoided in the residential areas so that severity of roadcollisions can be minimized.

Statistics of road collisions also reveal that untrained and unqualified drivers are also adversely affecting road safety. They are resulting in serious traffic hazards, which ultimately lead to collisions, death, and injuries. Therefore, it is very important to implement a strict policy for training drivers, especially those who spend more time on roads, such as taxi drivers, truck drivers, etc. Although this is an enforcement issue, and it should be taken care of more seriously by providing better facilities and training/skilling and evaluation/testing opportunities. Fig. 17 shows thestatistics of road collisions of 2016, 2017, and 2018 on the driver's license, such as drivers with license, drivers without a license, drivers with learner's license, etc.

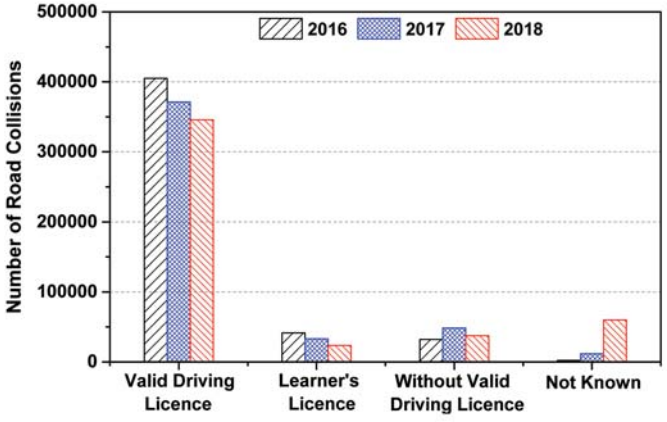

Fig. 17 Relation between driving license and number of road collisions (MoRTH, 2018)

Fig. 17 shows that drivers with a valid driving license (~75%) were responsible for most collisions in all three years. This shows the poor training of the drives along with the carelessness of drivers. This can be avoided by rigorous training of drivers and stricter license issuing authorities. However, falling trends inthe number of collisions in recent years show that road users are paying attention to traffic rules and regulations. Although the number of collisions due to drivers without driving license is, however, policies should be made to cut down this number to zero.

In most cases, minors without driving licenses are responsible for road collisions. This can also be seen in the next category as drivers with learner's licenses. Drivers with learner licenses should be given limited access to the roads so that casualties in road collisions can be reduced.

Statistics of road collisions show that non-usage safety measures such as helmets and seatbelts do not contribute to the number of road collisions; however, these measures significantly affect road collisions. In most of the collisions of two-wheelers, it has been observed that non-usage of the safety measures are responsible for more casualties and major injuries (Jain et al., 2009). Fig. 17 shows the number of persons killed in road collisions in 2017 and 2018 due to non-usage safety measures such as helmets and seatbelts. This figure indicates that non-wearing of helmets is the main cause of deaths in two-wheeler collisions, increasing YoY. In 2018, more than 28% of road collision casualties were mainly due to the non-wearing of helmets. This fig. also shows an interesting trend that the number of deaths of drivers is relatively higher than that of passenger deaths, which shows more collisions of two-wheelers with single occupancy. Seatbelts are another safety device that is mandatory for both the driver and the persons in vehicles other than two-wheelers and three-wheelers. In contrast to helmets, fatalities due to non-wearing of the seat belt in four-wheelers are relatively lower; however, four-wheelers involve more passengers death than the driver.

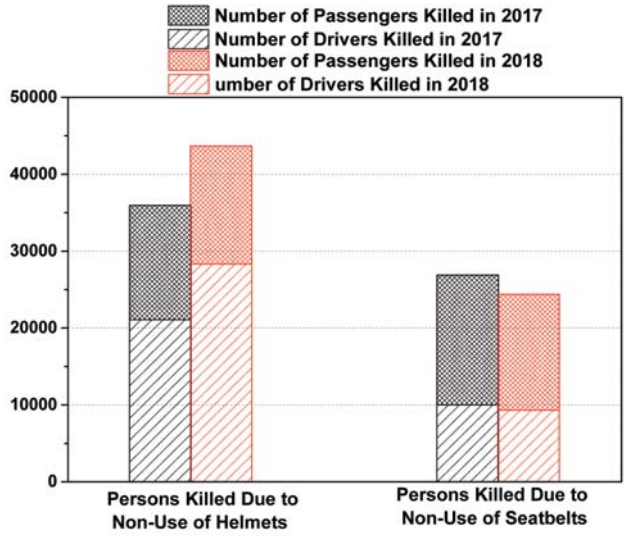

Fig. 18 Role of non-usage of safety measures in road collision casualties in 2017 and 2018 (MoRTH, 2018)

Fig. 18 shows the effect of weather conditions on the number of road collisions, the number of persons injured and killed in road collisions in 2017 and 2018. Weather condition affects road surface condition and the motorist's visibility, thereby increasing the chances of mishaps. Adverse weather conditions such as heavy rain, thick fog, and hail storms make driving riskier as visibility reduces and the road surface gets slippery. Fig. 18 shows that weather conditions do not contribute much to road collisions because most of the road collisions in 2017 and 2018 happened in sunny weather conditions. In sunny weather conditions, the drivers have clear road visibility, which sometimes becomes the cause of road collision due to overspeeding or lack of focus of roads. Other than sunny weather conditions, most of the collisions happen in rainy conditions. Slippery roads and poor visibility are the main cause of collisions in rainy weather conditions. Foggy weather conditions also contribute to road collisions, in which poor visibility is the most common cause of the collisions. In rainy and foggy weather conditions, most collisions involve a vehicle-to-vehicle collision, resulting in severe injury to the drivers and passengers, which sometimes leads to death. Compared to collisions in sunny weather conditions, the severity of collisions in rainy or foggy weather conditions is relatively more, which can be avoided by improving the vehicle safety measures and road infrastructure.

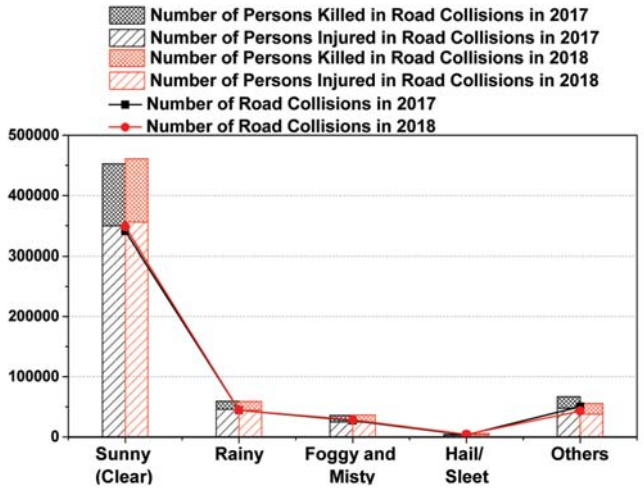

Fig. 19 Effect of weather conditions on the number of road collisions, number of persons injured and killed in road collisionsin 2017 and 2018 (MoRTH, 2018)

In India, most of the population lives in a rural area, which was ~70% in 2011 (Kumar et al., 2020; WHO, 2013; TV2035, 2016). The remaining 30% of India's population lives in urban areas. Most urban areas, including metro cities, have higher population density, resulting in vehicular traffic on roads. This leads to more road collisions compared to the rural areas. Urban areas are more involved in social and economic activities than rural areas, leading to more travel during a year. This is another important factor behind the higher number of road collisions in urban areas. Fig. 19 shows the comparison of the number of collisions, number of persons injured, and number of deaths in road collisions of rural and urban areas. This fig. also compares the statistics of road collisions of the last five years, i.e., 2014 to 2018.

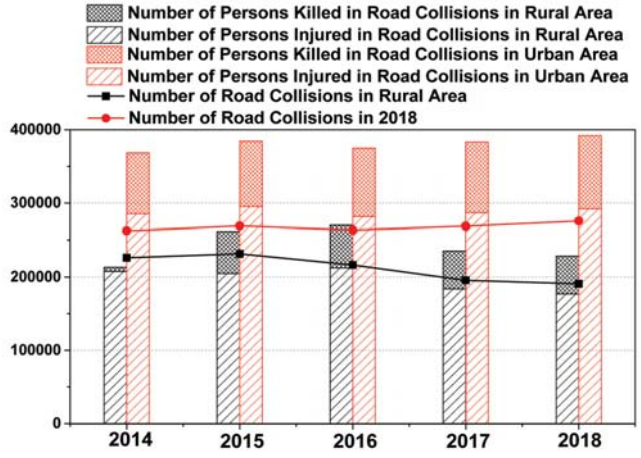

Fig. 19 Road collision statistics of rural and urban areas (MoRTH, 2018)

Fig. 19 shows that the number of collisions in urban areas remained almost constant in the last five years; however, the number of collisions in rural areas shows a slight reduction. This might be due to increased awareness about traffic rules and regulations in rural areas. Improvement of road infrastructure in rural areas might be another important reason for a relatively lower number of collisions in recent years. Although the number of collisions and number of persons injured in the collisions in rural areas has decreased in recent years, continuously increasing fatalities in rod collisions in rural areas is critical, requiring serious attention. Increased speed limit and motorization due to better road infrastructure in rural areas might be responsible for this trend. Compared to rural areas, the number of persons injured in road collisions and the number of casualties isrelatively more stable in urban areas.

4. Gaps in Road Safety Scenario

There has been a remarkable lack of interest amongst researchers and practitioners in designing a transport system against performance criteria and emphasizes the safety aspects of the road transport sector (Rujin et al., 2019; Christ, 2020). This includes efforts from both the automotive manufacturers as well as road infrastructure development authorities. The previous section shows that collisions mostly happen due to human errors; however, many collisions can be avoided by improving vehicle safety measures and road infrastructure. Road trauma continues to increase severe social and economic issues globally. Worldwide, the WHO (2004) estimates road collision costs (including vehicle and other damage, health expenditure, and waste production) at ~518 billion USD (WHO, 2004). Many researchers (Flahaut, 2004; Noland, 2003; Noland and Oh, 2004; Noland and Quddus, 2004) proposed that infrastructure improvements have effectively reduced the total number of fatalities and injuries. Road safety measures have to be taken on a priority basis to arrest and reverse the rising road fatalities in India (Malyshkina and Mannering, 2010). Driver training, which would ensure safe driving, should be encouraged (Berg et al., 2004; Katila et al., 2004; Singh, 2017).

Road traffic signs and signals need to be periodically checked. Road dividers, barriers should be used to prevent crossover of traffic. Speed limits should be strictly enforced. Driver safety awareness campaigns for seat belts and helmets need to be expedited. Safety devices such as antilock braking systems (ABS), airbags, and electronic stability control (ESC) need to be incorporated even for low-end vehicles to make them safer. Traffic management with collision avoidance and driver warning systems are required to reduce fatalities. Functional collision investigation centers and trauma facilities are required along the highways. The role of Intelligent Transportation Systems (ITS), particularly in communicating information to all relevant stakeholders (hospitals, police, etc.) in case of collisions, is very important. A suitable guideline for adopting advanced engine technologies should also be issued for sustainable transport systems (Singh and Agarwal, 2018). All vehicles should be checked for fitness, and Regional Transport Office (RTO) officials should be trained properly to do a sincere job. Adequate staffing of safety personnel in RTO is necessary. There are numerous active (Table 1) and passive (Table 2) safety

Table 1 Active safety technologies (TV 2035, 2016)

SN	Technology	Description	Remarks
1	Adaptive Front Lighting (AFS)	The AFS helps improve visibility during nighttime driving.	The technology is used for all vehicles.
2	Collision Avoidance	A collision avoidance system uses radar and sometimes laser and camera sensors to prevent an imminent crash.	Technology has been introduced for cars and sports utility vehicles (SUVs).
3	Anti-Lock Braking System	ABS allows the wheels to maintain tractive contact with the road surface and avoid uncontrolled skidding.	They are used for luxury cars and being introduced for small cars and SUVs.
4	Roll-Over Protection	Roll-over protection refers to operator compartment frames intended to protect vehicle occupants from injuries caused by vehicle roll-over.	They are used for light commercial vehicles (LCV) and heavy commercial vehicles (HCV) vehicles.
5	Electronic Stability Control	ESC is a computerized technology that improves a vehicle's stability by detecting and reducing loss of traction.	Used for LCV and HCV vehicles
6	Air Bags	Air-bag is an occupant restraint system consisting of a flexible fabric envelope or cushion designed to inflate rapidly during a collision.	Used for some passenger cars and SUVs
7	Tyre Pressure Monitoring	It is an electronic system designed to monitor the air pressure in the pneumatic tires on various vehicles.	Used for some vehicles
8	Driver Assist	Help the driver in navigation or parking.	Used for Passenger Cars

Table 2 Passive safety technologies (TV2035, 2016)

SN	Technology	Description
1	Road markings and dividers	To indicate the proper alignment of roads
2	Adequate run-off area and shoulders on the highways	For the safety of vehicles with break-down.
3	Use of guard rails or Jersey barriers	To prevent vehicles from going off-road
4	Material handling equipment for keeping vicinity of roadside free from debris and other obstructions	To prevent collisions
5	Collapsible lighting columns and signs mounted on shear bolts or made of yielding material	Designed for the impact of vehicles
6	Safety barriers to contain vehicles within lanes to prevent a head-on collision.	Designed for the impact of vehicles
7	Transitional Roads	Transitional roads connecting higher-speed roads with lower-speed roads encourage drivers to slowdown in good time
8	Rumble strips, speed bumps, visual warnings in the pavement and round-about	These assorted technologies can be used to improve safety

technologies adapted in vehicles to improve safety in the transport sector and the vehicles.

While active technologies are used in selected vehicles, passive technologies benefit all types of vehicles. Peña-García et al. (2012) studied the effect of the AFS on-road collisions and emphasized the features of AFS. They reported that AFS is an automatic system in which the system manages the way to light in each condition because manual control of such systems will increase the complexity of these systems. Delay in the manual reaction may also increase the chances of collisions; therefore, AFS systems are more suitable for lighting in modern vehicles. Recently, Chen et al. (2020) proposed a hybrid system of lighting in which several sensors are used to detect natural light. This system illuminates the LEDs when the sensor detects alow level of natural light. Such systems have reduced the probability of collisions in rainy/foggy environments.

5. Safety Roadmap for India

Road safety has been a priority for several years for policymakers in India. As part of the 'Road Safety Action Plan 2015-2017, a target was set to reduce the number of fatalities on Indian roads by 50%. The announcement was accompanied by concerted action on the part of all stakeholders. The following plancan be undertaken in the short-term, medium-term, and long-term to improve India's road safety (Table 3). Recent collisions data clearly shows the effect of several short-term solutions such as speed governors on public transport vehicles to avoid the collisions of public transport vehicles, stricter & uniform driving license examination, compulsory airbags for all passengers, etc., on collisions. These solutions have reduced the number of collisions and casualties in road collisions (Castillo and Vilke, 2016). In the last few years, the government of India (GoI) has started uniform driving license policies for improving driver's training.There are 29 model institutes of driving training and research (IDTR) in states/U.T.s planned by GoI in which 16 IDTRs are operational.

Similarly, there arefiveregional driving training centers (RDTC) in States/U.T.s to improve driver's training. Ministry of road transport and highways are planning to setup several driving training centers (DTC) at the district level to train drivers, especially commercial vehicle drivers, to strengthen overall mobility on roads. For developing these technologies and implementing these solutions in the road transport sector, the ministry of road transport and highways has amended the laws, which can be seen in the reports issued by the ministry (MoRTH, 2013; MoRTH, 2018).

Table 3 Agenda for improving safety road map of India (TV2035, 2016)

S N.	Technologies	Short Term (1-5 Years)	Medium Term (5-10 Years)	Long Term (10-20 Years)
i	Improving the indoor air quality of the cabin by using appropriate gas sensors and appropriate air changes in the cabin with the help of an onboard air-conditioning system.	✓		
ii	Advanced Electronic control system, which includes an anti-lock braking system and steering system, avoids skidding and slipping on slippery roads.	✓		
iii	Use of speed governors on public transport vehicles so that collisions due to over-speeding can be avoided.	✓		
iv	Sensors for windshield visibility (Visual aids for better nighttime and rain vision)	✓		
v	Stricter & uniform driving license examination	✓		
vi	Compulsory airbags for all passengers	✓		
vii	Low-cost airbag development	✓		
viii	Within vehicle communication systems	✓		
	(a) Vehicle-to-vehicle collision avoidance and platooning		✓	
	(b) Driver assistance·		✓	
	• Active braking·			
	• Active steering for collision avoidance and lane departure·	✓		
	• Automation of stop-and-go traffic situations			
	(c) Some advanced tools can be provided which may indicate the following warnings to avoid collision			
	• Rear-end collision warning	✓		
	• Roadway departure warning	✓		
	• Lane change/ Lane merge collision warning		✓	
	• Intersection collision warning	✓		
	• Rail-road crossing collision warning		✓	
	• Vision enhancement		✓	
	• Location-specific warnings		✓	
	• Collision notifications		✓	
	• Vehicle-to-infrastructure communication	✓		
ix	Safety Impacting: (potential to distract or aid the driver) for navigation and routing, real-time traffic information, driver comfort, and driver convenience features.		✓	
x	Development of efficient parking spaces throughout the country	✓		
xi	Training of drivers for safety: National unified database for issuing driving license	✓		
xii	Pot-hole free and well-maintained roads		✓	
xiii	Situational aware vehicles			✓
xiv	Commercial vehicle services: Vehicle stability, vehicle diagnostics, driver condition monitoring, cargo identification, automated transactions, safety recorder.	✓		
xv	Transit: obstacle and pedestrian detection, precision docking, passenger monitoring, passenger information.		✓	
xvi	Supporting Services: low friction warning, longitudinal control, lateral control.			✓

Increasing the penalty for violation of road safety laws is an important move taken by the MoRTH. The effect of these initiatives isvisible on accidental statistics of Indian roads (MoRTH, 2018).

6. Emerging Technologies for Safer Road Transport

It is required to develop an efficient and integrated traffic management system to control and regulate many vehicles operating on Indian roads. Reduction in traffic congestion and optimum use of existing capacity is a major challenge for the road transport sector's relevance. Estimates suggest that "road congestion costs, including commuting and leisure traffic, and business and freight traffic," affect the economy significantly (Matthias, 2011; Harriet et al., 2013; Weisbrod and Fitzroy, 2011). Several effective plans have already been developed; however, it is essential for a safe and efficient transportation system to have a traffic masterplan, which should control vehicular movement with higher levels of safety (Agarwal et al., 2020). The stakeholders, including public authorities responsible for providing and maintaining road infrastructure, vehicle manufacturers, individual drivers, and end-users of transport, must plan these safety measures. Many emerging technologies will eventually make the road transport sector safer than it is today.Some of these technologies, such as electronic toll booth, vehicle speed limiting devices, ABS for better vehicle stability during brake, adaptive cruise control, rear-mounted radar, etc., have already been implemented on Indian roads. These technologies have significantly affected road transport safety and reduced the number of collisions and casualties involved with road collisions (Singh, 2017; Ryder et al., 2017; Sivasankaran and Balasubramanian, 2020; Pal et al. 2018). These newer technological interventions include the following technologies:

(a) Electronic Brake Force Distribution: Electronic brake distribution (EBD) is a braking system, which adjusts braking according to the situation. EBD gives superior control and stability, which is useful in an emergency. Unlike most braking systems, which distribute brake force through mechanical control, EBD applies brake force precisely through electronic controls. It recognizes that driving conditions during braking situations since vehicle weight distributions are unique and constantly changing. The EBD control works with ABS, ensuring the most effective distribution of brake force between the brakes of the front and the rear wheels.
   - When braking around a corner, it also controls the brake force on the left and the right wheels, helping maintain vehicle stability.
   - The ABS electronic control unit (ECU) controls braking electronically.

(b) Self-driving and situationally aware vehicles.
(c) Collision avoidance and mitigation systems.
(d) Adaptive cruise control.
(e) Vehicle-to-vehicle communication systems.
(f) Speed limiting devices.
(g) In case of collisions, the vehicle could even transmit a distress signal to the nearest emergency rescue center.
(h) Passive safety for pedestrians and cyclists.
(i) Rear-mounted radar.
(j) Night vision with pedestrian detection and automatic high-beam control.
(l) Driverless car uses sensors to follow area maps and drive to the desired destination.
(m) Vehicle Stability Control (VSC): VSC begins to over-steer or under-steer because of an emergency rolling avoidance measure, or by excessive speed in a corner, VSC will automatically activate. By adjusting the engine's power output and braking each wheel independently, VSC helps the vehicle return to a 'zone of stable operation.'
(n) Regular maintenance of roads and use of appropriate safety measures for designing roads: This is another important aspect, which affects the road

Conclusions

India still has a long way to go when it comes to the safety of passengers, vehicles, and pedestrians. There is a need to adopt a multi-pronged strategy to address road safety in India in all seriousness based on 4E's of road. These include (i) education of drivers, (ii) enforcement of laws, (iii) engineering for roads as well as vehicles, and (iv) emergency care during road collisions. This article suggests adopting a multi-pronged approach to road safety, which encompasses traffic management, design, and quality of road infrastructure, application of intelligent transport systems, safer vehicles, law enforcement, effective and quick response to road collisions, etc. Many automotive manufacturers in India have also started investing substantially in developing new and advanced safety technologies to prevent collisions. The introduction of such technologies as standard fitment on vehicles would bring significant benefits to road safety. However, conventional vehicles are mostly not equipped with all known safety features that are available commercially. Both OEM and customers are responsible for this because of the more demand for low price vehicles, which needs significant attention. Shortly, safety systems should also become mandatory for all Indian vehicles. More awareness programs about the importance of safety devices in reducing the fatality of accidents are also necessary for the customers. In India, a new department needs to be setup for road collision/crash investigations to analyze the cause of collisions. This will help suggest and enforce preventive measures to avoid such collisions in the future. Methods to reduce road collisions need to be developed using real-world road collision data in India and similar countries. There is a need for the active involvement of all stakeholders to promote policy reform and implementation of road safety measures. Comprehensively addressing road safety underscores the need to involve multiple agencies/ sectors like health, transport, and police because the safety and security of vehicles areof paramount importance for the nation's economic development.

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