Chapter 42

Accident Studies

42.1 Overview

This lecture covers one of the most important negative impact of transportation system, namely the accidents. This lecture first presents some introductory stuff including some salient accident statistics, causes of accidents, accident data collection, accident reconstruction, safety measures and safety audit.

42.2 Introduction

The problem of accident is a very acute in highway transportation due to complex flow pattern of vehicular traffic, presence of mixed traffic along with pedestrians. Traffic accident leads to loss of life and property. Thus the traffic engineers have to undertake a big responsibility of providing safe traffic movements to the road users and ensure their safety. Road accidents cannot be totally prevented but by suitable traffic engineering and management the accident rate can be reduced to a certain extent. For this reason systematic study of traffic accidents are required to be carried out. Proper investigation of the cause of accident will help to propose preventive measures in terms of design and control.

42.2.1 Objectives of accident studies

Some objectives of accident studies are listed below:

1. To study the causes of accidents and suggest corrective measures at potential location

2. To evaluate existing design

3. To compute the financial losses incurred

4. To support the proposed design and provide economic justification to the improvement suggested by the traffic engineer

5. To carry out before and after studies and to demonstrate the improvement in the problem.

42.2.2   Causes of road accidents

The various causes of road accidents are:

1. **Road Users** - Excessive speed and rash driving, violation of traffic rules, failure to perceive traffic situation or sign or signal in adequate time, carelessness, fatigue, alcohol,sleep etc.

2. **Vehicle** - Defects such as failure of brakes, steering system, tyre burst,lighting system .

3. **Road Condition** - Skidding road surface, pot holes, ruts.

4. **Road design** - Defective geometric design like inadequate sight distance, inadequate width of shoulders, improper curve design, improper traffic control devices and improper lighting,.

5. **Environmental factors** -unfavorable weather conditions like mist, snow, smoke and heavy rainfall which restrict normal visibility and and makes driving unsafe.

6. **Other causes** -improper location of advertisement boards, gate of level crossing not closed when required etc..

42.2.3   Accident statistics

The statistical analysis of accident is carried out periodically at critical locations or road stretches which will help to arrive at suitable measures to effectively decrease accident rates. It is the measure (or estimates) of the number and severity of accident. These statistics reports are to be maintained zone-wise. Accident prone stretches of different roads may be assessed by finding the accident density per length of the road. The places of accidents are marked on the map and the points of their clustering (BLACK SPOT) are determined. By statistical study of accident occurrence at a particular road or location or zone of study for a long period of time it is possible to predict with reasonable accuracy the probability of accident occurrence per day or relative safety of different classes of road user in that location. The interpretation of the statistical data is very important to provide insight to the problem. The position of India in the year 2009 in country-wise number of person killed per 100000 populations as shown in
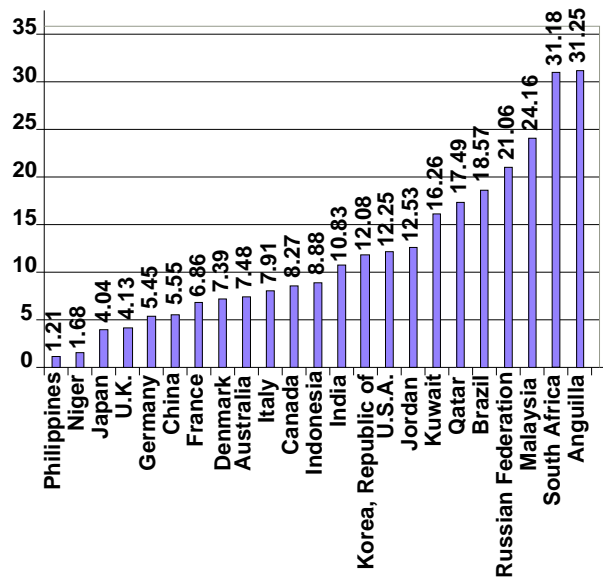
Figure 42:1: Country-wise number of person killed per 100000 populations (Ref. Ministry of Road Transport and Highways Transport Research Wing)

the Figure 42:1 and the increase in rate of accident from year 2005 to year 2009 is shown in the table. 42:1. In 2009, 14 accidents occurred per hour.   Figure 42:2 and 42:3 gives the percent of accident occurring from a specific vehicle class and the causes of accident in the form of pie-chart. Since the data collection of accident is mostly done by the traffic police its the users who are put to blame in majority of cases. Thus such statistical records are not much useful for the traffic engineer.

42.3   Accident Analysis

42.3.1   Accident data collection

The accident data collection is the first step in the accident study. The data collection of the accidents is primarily done by the police. Motorist accident reports are secondary data which are filed by motorists themselves. The data to be collected should comprise all of these parameters:

1. **General** - Date, time, person involved in accident, classification of accident like fatal, serious, minor

2. **Location** - Description and detail of location of accident

Table 42:1: Number of Accidents and Number of Persons Involved : 2001 to 2009(Ref. Ministry of Road Transport and Highways Transport Research Wing)

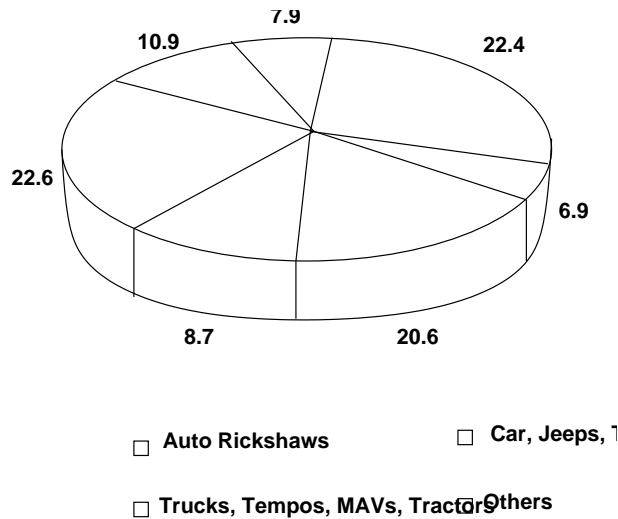| Year | No. of Accidents | | No. of persons affected | | Accident severity (No. of persons killed per 100 accidents) |
	Total	Fatal	Killed	Injured	
2005	4,39,255	83,491	94,968	4,65,282	22
2006	4,60,920	93,917	1,05,749	4,96,481	23
2007	4,79,216	1,01,161	1,14,444	5,13,340	24
2008	4,84,704	1,06,591	1,19,860	5,23,193	25
2009	4,86,384	1,10,993	1,25,660	5,15,458	25.8

Figure 42:2: Percent share in total road accident by type of motor vehicle involved (Primary responsible) in year 2009 (Ref. Ministry of Road Transport and Highways Transport Research Wing)
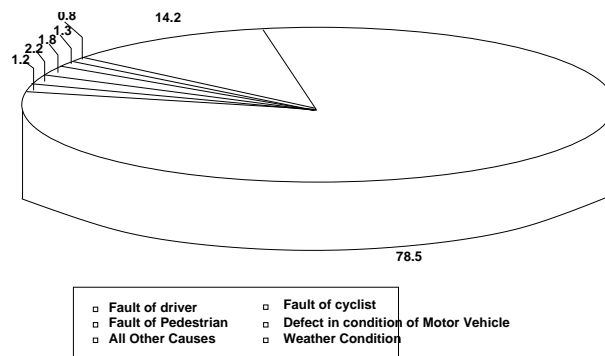
Figure 42:3: Causes of road accident in year 2009 (Ref. Ministry of Road Transport and Highways Transport Research Wing)

3. **Details of vehicle involved** - Registration number, description of vehicle, loading detail, vehicular defects

4. **Nature of accident** - Details of collision, damages, injury and casualty

5. **Road and traffic condition** - Details of road geometry, surface characteristics,type of traffic, traffic density etc..

6. **Primary causes of accident** - Details of various possible cases (already mentioned) which are the main causes of accident.

7. **Accident cost** - Financial losses incurred due to property damage, personal injury and casualty

These data collected need proper storing and retrieving for the following purpose. The purposes are as follows:

1. Identification of location of points at which unusually high number of accident occur.

2. Detailed functional evaluation of critical accident location to identify the causes of accidents.

3. Development of procedure that allows identification of hazards before large number of accidents occurs.

4. Development of different statistical measures of various accident related factors to give insight into general trends, common casual factors, driver profiles, etc.

42.3.2   Accident investigation

The accident data collection involves extensive investigation which involves the following procedure:

1. **Reporting:** It involves basic data collection in form of two methods:

   (a) **Motorist accident report** - It is filed by the involved motorist involved in all accidents fatal or injurious.

   (b) **Police accident report** - It is filed by the attendant police officer for all accidents at which an officer is present. This generally includes fatal accidents or mostly accidents involving serious injury required emergency or hospital treatment or which have incurred heavy property damage.

2. **At Scene-Investigation:** It involves obtaining information at scene such as measurement of skid marks, examination of damage of vehicles, photograph of final position of vehicles, examination of condition and functioning of traffic control devices and other road equipments.

3. **Technical Preparation:** This data collection step is needed for organization and interpretation of the study made. In this step measurement of grades, sight distance, preparing drawing of after accident situation, determination of critical and design speed for curves is done.

4. **Professional Reconstruction:** In this step effort is made to determine from whatever data is available how the accident occurs from the available data. This involves accident reconstruction which has been discussed under Section No.7 in details. It is professionally referred as determining behavioral or mediate causes of accident.

5. **Cause Analysis:** It is the effort made to determine why the accident occurred from the data available and the analysis of accident reconstruction studies..

42.3.3   Accident data analysis

The purpose is to find the possible causes of accident related to driver, vehicle, and roadway. Accident analyses are made to develop information such as:

1. Driver and Pedestrian - Accident occurrence by age groups and relationships of accidents to physical capacities and to psychological test results.

2. Vehicle - Accident occurrence related to characteristic of vehicle, severity, location and extent of damage related to vehicles.

3. Roadway conditions - Relationships of accident occurrence and severity to characteristics of the roadway and roadway condition and relative values of changes related to roadways.

It is important to compute accident rate which reflect accident involvement by type of highway. These rates provide a means of comparing the relative safety of different highway and street system and traffic controls. Another is accident involvement by the type of drivers and vehicles associated with accidents.

1. **Accident Rate per Kilometer :**
   On this basis the total accident hazard is expressed as the number of accidents of all types per km of each highway and street classification.

$$R = \frac{A}{L} \tag{42.1}$$

   where, R = total accident rate per km for one year, A = total number of accident occurring in one year, L = length of control section in kms

2. **Accident involvement Rate :**
   It is expressed as numbers of drivers of vehicles with certain characteristics who were involved in accidents per 100 million vehicle-kms of travel.

$$R = \frac{N \times 100000000}{V} \tag{42.2}$$

   where,R = accident involvement per 100 million vehicle-kms of travel, N = total number of drivers of vehicles involved in accidents during the period of investigation and V = vehicle-kms of travel on road section during the period of investigation

3. **Death rate based on population :**
   The traffic hazard to life in a community is expressed as the number of traffic fatalities per 100,000 populations. This rate reflects the accident exposure for entire area.

$$R = \frac{B \times 100000}{P} \tag{42.3}$$

   where, R = death rate per 100,000 population, B = total number of traffic death in one year and P = population of area

4. **Death rate based on registration :**

   The traffic hazard to life in a community can also be expressed as the number of traffic fatalities per 10,000 vehicles registered. This rate reflects the accident exposure for entire area and is similar to death rate based on population.

   $$R = \frac{B \times 10000}{M} \tag{42.4}$$

   where, R = death rate per 10,000 vehicles registered, B = total number of traffic death in one year and M = number of motor vehicles registered in the area

5. **Accident Rate based on vehicle-kms of travel :**

   The accident hazard is expressed as the number of accidents per 100 million vehicle km of travel. The true exposure to accident is nearly approximated by the miles of travel of the motor vehicle than the population or registration.

   $$R = \frac{C \times 100000000}{V} \tag{42.5}$$

   where, R = accident rate per 100 million vehicle kms of travel, C = number of total accidents in one year and V = vehicle kms of travel in one year

Numerical Example

The Motor vehicle consumption in a city is 5.082 million liters, there were 3114 motor vehicle fatalities, 355,799 motor vehicle injuries, 6,721,049 motor vehicle registrations and an estimated population of 18,190,238. Kilometer of travel per liter of fuel is 12.42 km/liter. Calculate registration death rate, population death rate and accident rate per vehicle km.

Solution   Approximate vehicle kms of travel = Total consumption o fuel × kilometer of travel per liter of fuel =$5.08 \times 10^9 \times 12.42 = 63.1 \times 10^9$ km.

1. Registration death rate can be obtained from the equation

   $$R = \frac{B \times 10,000}{M}$$

   Here, R is the death rate per 10,000 vehicles registered, B (Motor vehicle fatalities) is 3114, M (Motor vehicle registered) is 6.72×10^6. Hence,

   $$R = \frac{3114 \times 10000}{6.72 \times 10^6} = 4.63$$

2. Population Death Rate can be obtained from the equation.

$$R = \frac{B \times 100,000}{P}$$

Here, R is the death rate per 100,000 population, B (Motor vehicle fatalities) is 3114, P (Estimated population) is= 18.2×10^6.

$$R = \frac{3114 \times 100000}{18.2 \times 10^6} = 17.1$$

3. Accident rate per vehicle kms of travel can be obtained from the equation below as:

$$R = \frac{C \times 100,000,000}{V}$$

Here, R is the accident rate per 100 million vehicle kms of travel, C (total accident same as vehicle fatalities) is 3114, V (vehicle kms of travel) is 63.1×10^9.

$$R = \frac{3114 \times 100 \times 10^6}{63.1 \times 10^9} = 4.93$$

42.4   Accident reconstruction

Accident reconstruction deals with representing the accidents occurred in schematic diagram to determine the pre-collision speed which helps in regulating or enforcing rules to control or check movement of vehicles on road at high speed. The following data are required to determine the pre-collision speed:

1. Mass of the vehicle

2. Velocities after collision

3. Path of each vehicle as it approaches collision point

Below in Figure 42:4 a schematic diagram of collision of two vehicles is shown that occur during turning movements. This diagram is also known as collision diagram. Each collision is represented by a set of arrows to show the direction of before and after movement. The collision diagram provides a powerful visual record of accident occurrence over a significant period of time. The collision may be of two types collinear impact or angular collision. Below each of them are described in detail. Collinear impact can be again divided into two types :
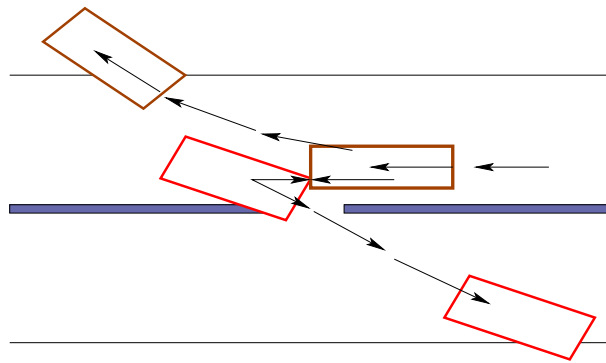
1. Rear end collision
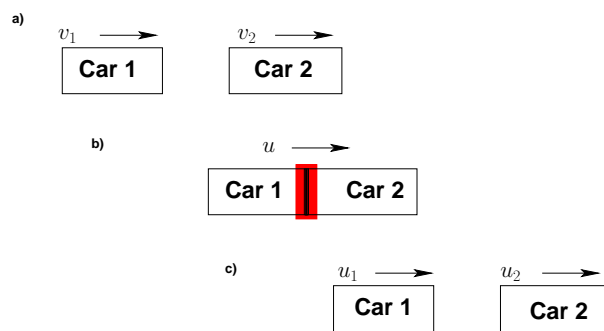
Figure 42:4: Collision diagram of two vehicles

Figure 42:5: Compression Phase

2. Head-on collision.

It can be determined by two theories:

1. Poisson Impact Theory

2. Energy Theory

42.4.1   Poisson impact theory

Poisson impact theory, divides the impact in two parts - compression and restitution. The Figure 42:5 shows two vehicles travelling at an initial speed of v_1 and v_2 collide and obtain a uniform speed say u at the compression stage. And after the compression stage is over the final speed is u_1 and u_2. The compression phase is cited by the deformation of the cars. From the Newtons law $F = ma$,

$$m_1 \frac{dv_1}{dt} = -F \quad \text{and} \quad m_2 \frac{dv_2}{dt} = F \tag{42.6}$$

where, m_1 and m_2 are the masses of the cars and F is the contact force. We know that every reaction has equal and opposite action. So as the rear vehicle pushes the vehicle ahead with

Figure 42:6: Force applied on each vehicle

force F. The vehicle ahead will also push the rear vehicle with same magnitude of force but has different direction. The action force is represented by F, whereas the reaction force is represented by $-F$ as shown in Figure 42:6. In the compression phase cars are deformed. The compression phase terminates when the cars have equal velocity. Thus the cars obtain equal velocity which generates the following equation:

$$m_1(u - v_1) = -P_c \ m_2(u - v_2) = P_c \tag{42.7}$$

where, $P_c \equiv \int_0^{\tau_c} F \ dt$ which is the compression impulse and τ_c is the compression time. Thus, the velocity after collision is obtained as:

$$u = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} \tag{42.8}$$

The compression impulse is given by:

$$P_c = \frac{m_1 m_2}{m_1 + m_2}(v_1 - v_2) \tag{42.9}$$

In the restitution phase the elastic part of internal energy is released

$$m_1(u_1 - u) = -P_r \tag{42.10}$$
$$m_2(u_2 - u) = P_r \tag{42.11}$$

where, $P_r \equiv \int_0^{\tau_r} F \ dt$ is the restitution impulse and τ_r is the restitution time. According to Poissons hypothesis restitution impulse is proportional to compression impulse

$$P_r = e \ P_c \tag{42.12}$$

Restitution impulse e is given by:

$$e = \frac{u_2 - u_1}{v_1 - v_2} \tag{42.13}$$

The total impulse is $P = P_c + P_r$

$$P = (1 + e)\frac{m_1 m_2}{m_1 + m_2}\Delta v \tag{42.14}$$

The post impact velocities are given by:

$$u_1 = u - e\frac{m_2}{m_1+m_2}\Delta v = v_1 - \frac{(1+e)m_2}{m_1+m_2}\Delta v \tag{42.15}$$

$$u_2 = u + e\frac{m_1}{m_1+m_2}\Delta v = v_2 + \frac{(1+e)m_1}{m_1+m_2}\Delta v \tag{42.16}$$

where $\Delta v = v_1 - v_2$. But we are required to determine the pre-collision speed according to which the safety on the road can be designed. So we will determine v_1 and v_2 from the given value of u_1 and u_2 .

Numerical Example

Two vehicles travelling in the same lane have masses 3000 kg and 2500 kg. The velocity of rear vehicles after striking the leader vehicle is 25 kmph and the velocity of leader vehicle is 56 kmph. The coefficient of restitution of the two vehicle system is assumed to be 0.6. Determine the pre-collision speed of the two vehicles.

Solution   Given that the: mass of the first vehicle (m_1) = 3000 kg, mass of the second vehicle (m_2) = 2500 kg, final speed of the rear vehicle (u_1) = 25 kmph, and final speed of the leader vehicle (u_2) = 56 kmph. Let initial speed of the rear vehicle be v_1, and let initial speed of the leader vehicle be v_2.

   Step 1:   From equation. 42.15,

$$25 = v_1 - \frac{(1.6)2.5(v_1 - v_2)}{(3 + 2.5)}$$
$$5.5v_1 - 4v_1 + 4v_2 = 137.5$$
$$4v_2 - 1.5v_1 = 137.5 \tag{42.17}$$

   Step 2:   From equation. 42.16,

$$56 = v_2 + \frac{(1.6)3(v_1 - v_2)}{(3 + 2.5)}$$
$$5.5\ v_2 + 4.8\ v_1 - 4.8v_2 = 308$$
$$4.8\ v_1 - 0.7\ v_2 = 308 \tag{42.18}$$

   Step 3:   Solving equations. 42.17 and 42.18, We get the pre collision speed of two vehicles as: $v_1 = 73$ kmph, and $v_2 = 62$ kmph.

   Step 4:   Initial speed of the rear vehicle, $v_1 = 73$ kmph, and the initial speed of leader vehicle, $v_2 = 62$ kmph. Thus from the result we can infer that the follower vehicle was travelling at quite high speed which may have resulted in the collision. The solution to the problem may be speed restriction in that particular stretch of road where accident occurred.

42.4.2   Energy theory

Applying principle of conservation of energy or conservation of momentum also the initial speed of the vehicle can be computed if the skid marks are known. It is based on the concept that there is reduction in kinetic energy with the work done against the skid resistance. So if the vehicle of weight W slow down from speed v_1 to v_2, then the loss in kinetic energy will be equal to the work done against skid resistance, where work done is weight of the vehicle multiplied by the skid distance and the skid resistance coefficient.

$$\frac{W(v_1^2 - v_2^2)}{2g} = W.f.S \tag{42.19}$$

where, f is the skid resistance coefficient and S is the skid distance. It also follows the law of conservation of momentum (m_1, v_1 are the mass and velocity of first vehicle colliding with another vehicle of mass and velocity m_2, v_2 respectively)

$$m_1 v_1 = m_2 v_2 \tag{42.20}$$

Numerical example

A vehicle of 2000 kg skids a distance of 36 m before colliding with a stationary vehicle of 1500 kg weight. After collision both vehicle skid a distance of 14 m. Assuming coefficient of friction 0.5, determine the initial speed of the vehicle.

   Solution: Let the weight of the moving vehicle is W_A, let the weight of the stationary vehicle is W_B, skid distance before and after collision is s_1 and s_2 respectively, initial speed is v_1, speed after applying brakes before collision is v_2 and the speed of both the vehicles A and B after collision is v_3, and the final speed v_4 is 0. Then:

1. After collision: Loss in kinetic energy of both cars = Work done against skid resistance (can be obtained from equation mentioned below). Substituting the values we obtain v_3.

$$
\begin{aligned}
\frac{(W_A + W_B) \times (v_3^2 - v_4^2)}{2g} &= (W_A + W_B).f.s_2 \\
\frac{(v_3)^2}{2g} &= 0.5 \times 14 = 7 \\
v_3 &= 11.71 m/s
\end{aligned}
$$

2. At collision: Momentum before impact = momentum after impact (can be obtained from equation. 42.20)

$$\frac{W_A.v_2}{g} = \frac{(W_A + W_B)v_3}{g}$$
$$v_2 = \frac{(W_A + W_B)v_3}{W_A}$$
$$v_2 = 20.5 m/s$$

3. Before collision (can be obtained from equation. 42.19): Loss in kinetic energy of moving vehicle = work done against braking force in reducing the speed

$$\frac{(W_A) \times (v_1^2 - v_2^2)}{2g} = W_A.f.s_1$$
$$\frac{(v_1^2 - v_2^2)}{2g} = 0.5 \times 36$$
$$v_1 = 27.8\ m/s = 100\ kmph$$

Ans: The pre-collision speed of the moving vehicle is 100 kmph.

42.4.3   Angular collision

Angular collision occurs when two vehicles coming at right angles collies with each other and bifurcates in different direction. The direction of the vehicles after collision in this case depends on the initial speeds of the two vehicles and their weights. One general case is that two vehicles coming from south and west direction after colliding move in its resultant direction as shown in Figure 42:7.

The mass of the car 1 is m_1 kg and the car 2 is m_2 kg and the initial velocity is v_1 m/s and v_2 m/s respectively. So as the momentum is the product of mass and velocity. The momentum of the car 1 and car 2 is m_1v_1 kgm/s and m_2v_2 kgm/s respectively. By the law of conservation of momentum the final momentum should be equal to the initial momentum. But as the car are approaching each other at an angle the final momentum should not be just mere summation of both the momentum but the resultant of the two, Resultant momentum = $\sqrt{(m_1v_1)^2 + (m_2v_2)^2}$ kg m/s. The angle at which they are bifurcated after collision is given by $\tan^{-1}(h/b)$ where h is the hypotenuse and b is the base. Therefore, the cars are inclined at an angle. Inclined at an angle = $\tan^{-1}(m_2v_2/m_1v_1)$. Now, since the mass of the two vehicles are same the final velocity will proportionally be changed. The general schematic diagrams of collision are shown in Figs. 42:8 to 42:10.
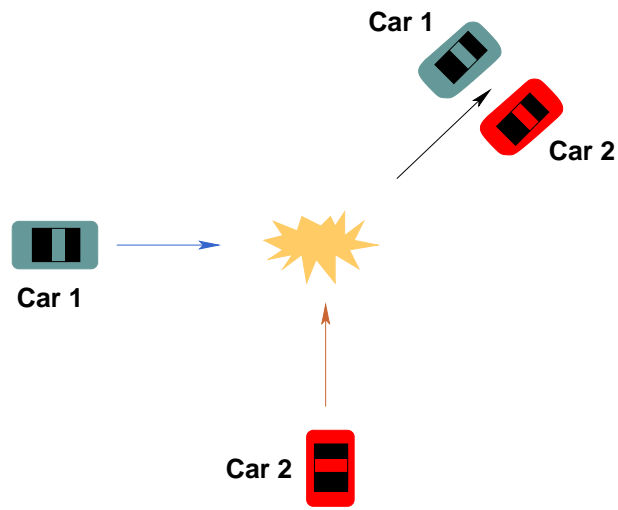
Figure 42:7: Angular collision of two vehicles resulting in movement in resultant direction
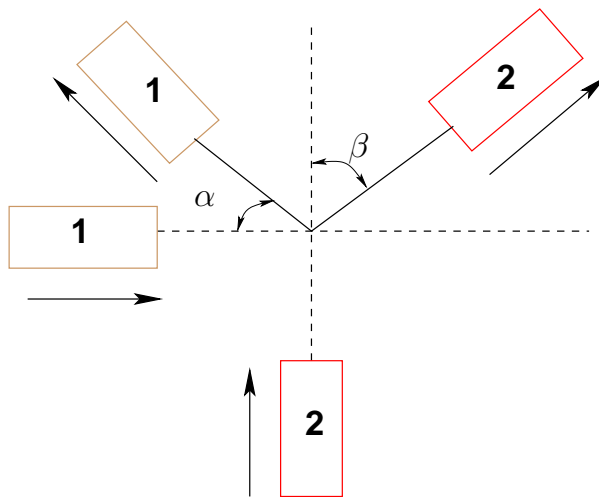

Figure 42:8: After collision movement of car 1 north of west and car 2 in east of north
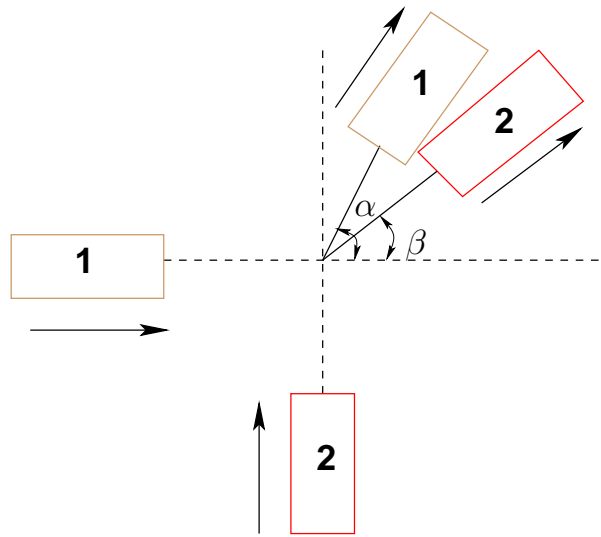
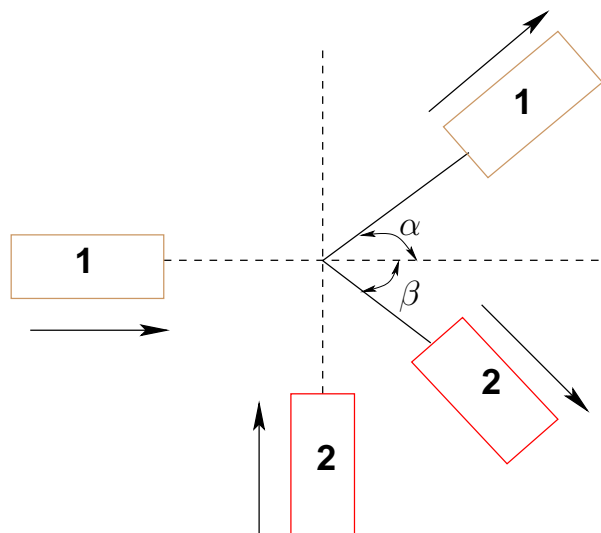Figure 42:9: After collision movement of car 1 and car 2 in north of east

Figure 42:10: After collision movement of car 1 north of east and car 2 in south of east

Numerical example

Vehicle A is approaching from west and vehicle B from south. After collision A skids 60^0 north of east and B skids 30^0 south of east as shown in Figure 42:10. Skid distance before collision for A is 18 m and B is 26 m. The skid distances after collision are 30m and 15 m respectively. Weight of A and B are 4500 and 6000 respectively. Skid resistance of pavement is 0.55 m. Determine the pre-collision speed.

Solution   Let: initial speed is v_{A1} and v_{B1}, speed after skidding before collision is v_{A2} and v_{B2}, speed of both the vehicles A and B after collision is v_{A3} and v_{B3}, final speed is v_{A4} and v_{B4} is 0, initial skid distance for A and B is s_{A1} and s_{B1}, final skid distance for A and B is s_{A2} and s_{B2}, and weight of vehicle A is W_A and Weight of vehicle B is W_B.

1. After collision: Loss in kinetic energy of each cars= Work done against skid resistance (can be obtained from equation. 42.19)

$$\frac{W_A v_{A3}^2}{2g} = W_A\ f\ s_{A2}$$

As $v_{A4} = 0$, it is not considered in the above equation

$$
\begin{aligned}
v_{A3} &= \sqrt{2gfs_{A2}} \\
v_{A3} &= 18\ m/s
\end{aligned}
$$

Similarly, we calculate v_{B3} using the similar formula and using s_{B2}

$$v_{B3} = 12.7\ m/s$$

2. At collision: Momentum before impact is momentum after impact (resolving along west-east direction and using equation. 42.20)

$$
\begin{aligned}
\frac{W_A}{g} \times v_{A2} + 0 &= \frac{W_B}{g}\cos B v_{B3} + \frac{W_A}{g}\cos A v_{A3} \\
v_{A2} &= \frac{W_B}{W_A}\cos B v_{B3} + \cos A v_{A3} \\
&= \frac{6}{4.5}\cos 30 \times 12.7 + \cos 60 \times 18 \\
v_{A2} &= 23.66\ m/s.
\end{aligned}
$$

Resolving the moments along south- north direction

$$\frac{W_B}{g} \times v_{B2} + 0 = \frac{W_A}{g} \sin A v_{A3} - \frac{W_B}{g} \sin B v_{B3}$$
$$v_{B2} = \frac{W_A}{W_B} \sin A v_{A3} - \sin B v_{B3}$$
$$= \frac{4.5}{6} \times \sin 60 \times 12.7 - \sin 30 \times 18$$
$$v_{B2} = 5.34 \; m/s$$

3. Before collision: Loss in kinetic energy of each cars= Work done against skid resistance (can be obtained from equation. 42.19)

$$\frac{W_A(v_{A1}^2 - v_{A2}^2)}{2g} = W_A.f.s_{A2}$$
$$v_{A1} = \sqrt{2gfs_{A1} + v_{A2}^2}$$
$$= 27.45 m/s = 99 \; km/hr$$

Similarly, using the same equation and using s_{B2}

$$v_{B1} = \sqrt{2gfs_{B1} + v_{B2}^2}$$
$$= 17.57 m/s = 63.26 \; km/hr$$

Answer: The pre-collision speed of the vehicle A (approaching from west) is $v_{A1} = 99$ km/hr and vehicle B (approaching from south) is $v_{B1} = 63.26$ km/hr.

42.5   Safety measures

The ultimate goal is to develop certain improvement measures to mitigate the circumstances leading to the accidents. The measures to decrease the accident rates are generally divided into three groups engineering, enforcement and education. Some safety measures are described below:

42.5.1   Safety measures related to engineering

The various measures of engineering that may be useful to prevent accidents are enumerated below

Visual guidance to driver

There is consecutive change of picture in drivers mind while he is in motion. The number of factors that the driver can distinguish and clearly fix in his mind is limited. On an average the perception time for vision is $1/16^{th}$, for hearing is $1/20^{th}$ and for muscular reaction is $1/20^{th}$. The number of factors that can be taken into account by organs of sense of a driver in one second is given by the formula below.

$$E = MV/L \tag{42.21}$$

where, M = No. of factors that can be taken into account by the organ of sense of driver for L m long, V = speed of vehicle in m/sec. Factors affecting drivers attention when he is on road can be divided into three groups:

1. Factors relating to the road elements of road that directly affect the driving of a vehicle are traffic signs, changes in direction of road, three legged intersection and various other things.

2. Factors connected with traffic Other vehicles, cycles, pedestrians.

3. Factors related indirectly to the vehicle motion Building and structures that strike the eye, vegetation, landscape, etc.

So using the laws of visual perception certain measures have been suggested:

1. Contrast in visibility of the road should be achieved by provision of elements that differ from its surrounding by colors, pattern such as shoulder strips, shoulder covered with grass, edge markings.

2. Providing road side vegetation is an effective means.

3. The visibility of crown of trees from a distant location is also very useful in visual guiding.

4. The provision of guard rails of different contrasting colors also takes drivers attention and prevent from monotonous driving.

Figure 42:11 and 42:12 is a visual guidance measure. Planting trees along side of roadway which has a turning angle attracts attention of the driver and signals that a turn is present ahead. The figure below is another example, when the direction of road has a hazardous at-grade intersection trees are planted in such a way that it seems that there is dense forest ahead and driver automatically tends to stop or reduce the speed of the vehicle so that no conflicts occur at that point. Driver tends to extrapolate the further direction of the road. So it is the responsibility of the traffic engineer to make the driver psychologically confident while driving that reduces the probability of error and prevent mental strain.
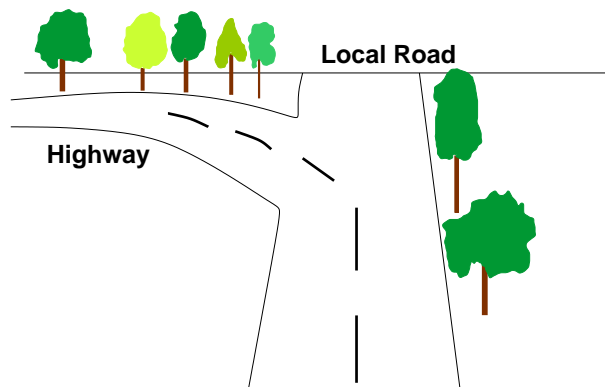
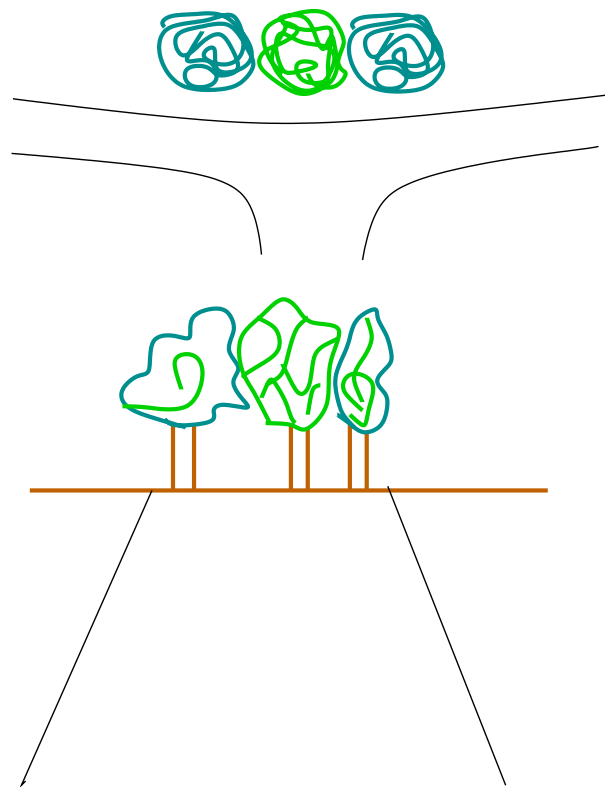Figure 42:11: Bifurcation of the highway

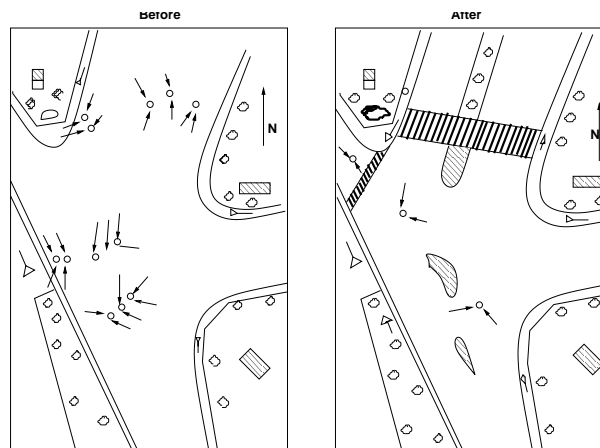Figure 42:12: Road seemed to be stopped by a dense forest

Figure 42:13: Diagram of accidents before and after reconstruction

Road reconstruction

The number of vehicles on the road increases from year to year, which introduces complications into organization of traffic, sharply reduces the operation and transportation characteristic of roads and lead to the growth of accident rate. This leads to the need of re constructing road. The places of accidents need to be properly marked so that the reconstruction can be planned accordingly. The Figure 42:13 shows that there were too many conflict points before which reduced to a few number after construction of islands at proper places. Reconstruction process may also include construction of a new road next to the existing road, renewal of pavement without changing the horizontal alignment or profile of the road, reconstruction a particular section of road. Few more examples of reconstruction of selected road section to improve traffic safety are shown in Figure 42:14. The Figure 42:14 (a) shows separation of direction of main stream of traffic from the secondary ones by shifting place of three-leg intersection, Figure 42:14(b) shows separation of roads with construction of connection between them and Figure 42:14(c) shows the construction of additional lane for turning vehicles. The plus sign indicates the conflict points before the road reconstruction has been carried out. The after reconstruction figure shows that just by little alteration of a section of road how the conflict points have been resolved and smooth flow of the vehicles in an organized manner have been obtained.

Channelization

The Channelization of traffic at intersection separates the traffic stream travelling in different direction, providing them a separate lane that corresponds to their convenient path and spreading as far as possible the points of conflict between crossing traffic streams. The traffic lanes
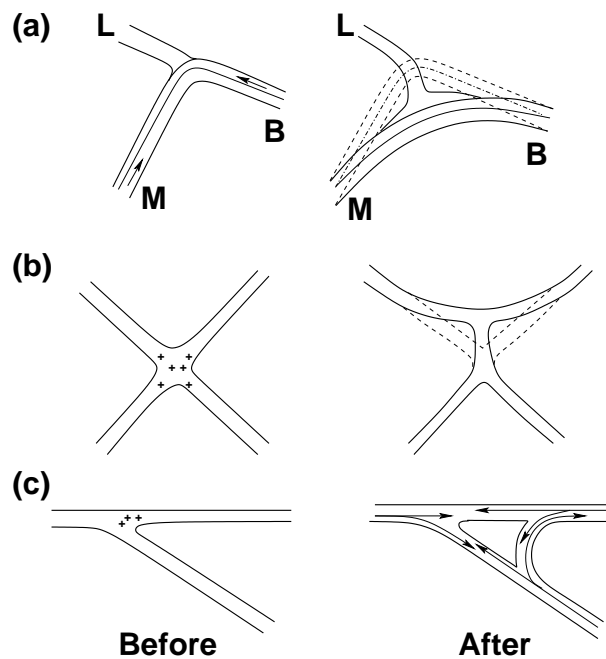
Figure 42:14: Road reconstruction technique

are separated by marking relevant lines or by constructing slightly elevated islands as shown in Figure 42:15. Proper Channelization reduces confusion. The number of decision required to be made by the driver at any time is reduced allowing the driver time to make next decision. The principles of proper channelized intersection are:-

1. The layout of intersection should be visibly clear, simple and understandable by driver.

2. Should ensure superiority to the vehicles using road of higher class.

3. Layout of intersection makes it necessary for a driver running through it to choose at each moment of time one of not more than two possible direction of travel. This is achieved by visual guidance, islands and markings.

4. The island provided should separate high speed, through and turning traffic flows.

5. The width of traffic lane should ensure unhampered turning to the big vehicles. Width of straight section without kerb should be 3.5 m and that of traffic lane near island is 4.5-5 m at entry and 6 m at exit.

6. Pedestrian crossing should be provided

a) Partially channelized intersection
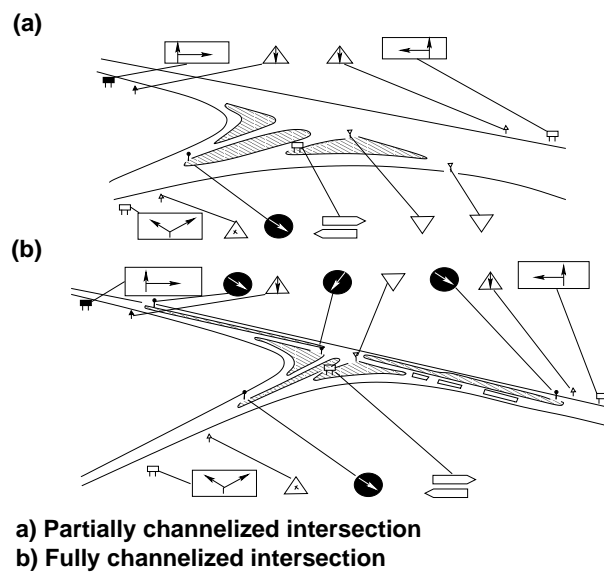**b) Fully channelized intersection**

Figure 42:15: Channelized Intersection ensuring safety

Road signs

Road signs are integral part of safety as they ensure safety of the driver himself (warning signs) and safety of the other vehicles and pedestrians on road (regulatory signs). Driver should be able to read the sign from a distance so that he has enough time to understand and respond. It is essential that they are installed and have correct shape, colour, size and location. It is required to maintain them as well, without maintenance in sound condition just their installment would not be beneficial. According to British investigation height of text in road sign should be

$$H \quad = \quad \frac{(N+6)v}{64} + \frac{3}{4}L$$

Where, N = No. of words on the sign, v = speed of vehicle (kmph), L = distance from which inscription should be discernible (m)

Other methods

Various other methods of traffic accident mitigation are described below:

1. **Street lighting**
   Street lightning of appropriate standard contributes to safety in urban area during night time due to poor visibility. Installation of good lighting results in 21% reduction in all accidents, 29% reduction in "all casualty" accidents, 21% reduction in "non pedestrian casualty" accidents, and 57% reduction in "pedestrian casualty" accidents.

2. **Improvement in skid resistance**

   If road is very smooth then skidding of the vehicles may occur or if the pavement is wet then wet weather crashes occur which account about 20-30%. Thus it is important to improve the skid resistance of the road. Various ways of increasing the skid resistance of road are by constructing high-friction overlay or cutting of grooves into the pavement.

3. **Road markings**

   Road markings ensure proper guidance and control to the traffic on a highway. They serve as supplementary function of road sign. They serve as psychological barrier and delineation of traffic path and its lateral clearance from traffic hazards for the safe movement of traffic. Thus their purpose is to provide smooth and safe traffic flow.

4. **Guide posts with or without reflector**

   They are provided at the edge of the roadway to prevent the vehicles from being off tracked from the roadway. Their provision is very essential in hilly road to prevent the vehicle from sliding from top. Guide posts with reflector guide the movement of vehicle during night.

5. **Guard rail**

   Guard rail have similar function as of guide post. On high embankments, hilly roads, road running parallel to the bank of river, shores of lake, near rock protrusion, trees, bridge, abutments a collision with which is a great hazard for a vehicle. It is required to retain the vehicle on the roadway which has accidentally left the road because of fault or improper operation on the part of the driver. Driver who has lost control create a major problem which can be curbed by this measure.

6. **Driver reviver stop**

   Driver reviver stop are generally in use in countries like U.S.A where driver can stop and refresh himself with food, recreation and rest. They play a very important part in traffic safety as they relieve the driver from the mental tension of constant driving. These stops are required to be provided after every 2 hour travel time.

7. **Constructing flyovers and bypass**

   In areas where local traffic is high bypasses are required to separate through traffic from local traffic to decrease the accident rate. To minimize conflicts at major intersections flyovers are required for better safety and less accident rate

8. **Regular accident studies**

   Based on the previous records of accidents the preventive measures are taken and after

that the data related to accidents are again collected to check the efficiency of the measures and for future implementation of further preventive measures.

42.5.2 Safety measures related to enforcement

The various measures of enforcement that may be useful to prevent accidents at spots prone to accidents are enumerated below. These rules are revised from time to time to make them more comprehensive.

Speed control

Checks on spot speed of all vehicles should be done at different locations and timings and legal actions on those who violate the speed limit should be taken

Training and supervision

The transport authorities should be strict while issuing licence to drivers of public service vehicles and taxis. Driving licence of the driver may be renewed after specified period, only after conducting some tests to check whether the driver is fit

Medical check

The drivers should be tested for vision and reaction time at prescribed intervals of time

42.5.3 Safety measures related to education

The various measures of education that may be useful to prevent accidents are enumerated below.

Education of road users

The passengers and pedestrians should be taught the rules of the road, correct manner of crossing etc. by introducing necessary instruction in the schools for the children and by the help of posters exhibiting the serious results due to carelessness of road users.

Safety drive

Imposing traffic safety week when the road users are properly directed by the help of traffic police as a means of training the public. Training courses and workshops should be organized for drivers in different parts of the country.

42.5.4   Safety audit

It is the procedure of assessment of the safety measures employed for the road. It has the advantages like proper planning and decision from beforehand ensures minimization of future accidents, the long term cost associated with planning is also reduced and enables all kinds of users to perceive clearly how to use it safely. Safety audit takes place in five stages as suggested by Wrisberg and Nilsson, 1996. Five Stages of Safety Audit are:

1. **Feasibility Stage** - The starting point for the design is determined such as number and type of intersection, relationship of the new scheme to the existing road, the relevant design standards.

2. **Draft Stage** - In this stage horizontal and vertical alignment, junction layout are determined. After the completion of this stage decision about land acquisition is taken.

3. **Detailed design stage** - Signing, marking, lighting, other roadside equipment and landscaping are determined.

4. **Pre-opening stage** - Before opening a new or modified road should be driven, walked or cycled. It should be done at different condition like bad weather, darkness.

5. **Monitoring of the road in use** - Assessment is done at the final stage after the road has been in operation for few months to determine whether the utilization is obtained as intended and whether any adjustment to the design are required in the light of the actual behavior of road users.

An example of safety audit is discussed below.

Road reconstruction safety audit

To estimate the effectiveness of improvement of dangerous section the number of accidents before and after is compared. To do this Chi Square test is used to check whether the experimental data meet the allowable deviation from the theoretical analysis. In the simplest case one group of data before and after road reconstruction is considered.

$$X^2 = \frac{(n_1 t_2 - n_2 t_1)^2}{t_1 t_2 (n_1 + n_2)} \geq X^2_{norm} \tag{42.22}$$

where, t_1 and t_2 = period of time before and after reconstruction of a stretch of road for which statistical data of accident is available, n_1 and n_2 = corresponding numbers of accident, X^2_{norm} = minimum values of Chi Square at which probability of deviation of laws of accident

Table 42:2: Relationship between P and X^2_{norm}

P	10	8	5	3	2	1	0.1
X^2_{norm}	1.71	2	2.7	3.6	4.25	5.41	9.6

occurrence after reconstruction P from the laws existing before reconstruction does not exceed permissible values (usually 5%) The relationship between P and X^2_{norm} is shown in Table. 42:2.

Numerical example

Before reconstruction of an at-grade intersection, there were 20 accidents during 5 years. After reconstruction there were 4 accidents during 2 years. Determine the effectiveness of the reconstruction.

Solution: Using Chi square test, we have (with P = 5 %)

$$X^2 = \frac{(20 \times 2 - 4 \times 5)^2}{5 \times 2(20 + 4)} = 1.67 \; < \; 2.7$$

Thus the statistical data available are not yet sufficient for considering with probability of 95 % that the relative reduction in number of accident is due to intersection reconstruction. Assuming one more accident occurs next year.

$$X^2 = \frac{(20 \times 3 - 5 \times 5)^2}{5 \times 3(20 + 5)} = 3.267 \; > \; 2.7$$

Therefore additional analysis confirms that the reduction in accident is due to road reconstruction.

42.6   Conclusion

This chapter provides an important subject of highway safety and accident studies. Everything a traffic engineer does, from field studies, planning and design; to control operation is related to the provision of the safety system for vehicular travel. This chapter gives an insight of how the analysis of traffic accident can be done from the viewpoint to reduce it by designing proper safety measure.

42.7   References

1. Road accidents in india, 2009.

2. V F Babkov. *Road Condition and traffic safety.* MIR Publishers, Moscow, 2019.

3. J Stannard Baker. *Traffic Accident Investigation Manual.* The traffic Institute Northwestern University, 2019.

4. Milan Batista. On the mutual coefficient of restitution in two car collinear collisions, 2006.

5. S K Khanna C E G Justo. *Highway Engineering.* Nem Chand and Bros, Roorkee, 2001.

6. K W Ogden, S Y Taylor. Traffic Engineering, and Australia. Management. Monash University. Melbourne. *Traffic Engineering and Management.* Monash University Melbourne, Australia, 2019.

7. Louis J Pignataro. *Traffic Engineering.* USA, 2019.