Safe Road Designs
Safety Principles and Applications

Geetam Tiwari
MoUD Chair Professor, TRIPP/CED, IIT Delhi
Outline

• RTC trend
• Traffic Safety theories
• Risk Factors
• Forgiving Highways
• Forgiving Urban Roads
Lessons from historical data: Traffic Death Rates: High Income Countries (OECD)

Source: death registration data

- New vehicle/road safety standards
- Seatbelt helmet speed alcohol
- Education+blackspots
- Independent agency
- Research centres
**INDIA: Safety Policies and RTC Fatalities**

**Estimated 30,00,000 hospitalised in 2018**

- **IRC 1934**
- **MVA 1939**
- **MVA1989**
- **NHAI Act 1988**
- **Sundar Committee 2005-7**
- **Supreme Court Committee 2014**
- **Amended MVA 2019**

Year:
- 1970
- 1975
- 1980
- 1985
- 1990
- 1995
- 2000
- 2005
- 2010
- 2015

Fatalities:
- 20,000
- 40,000
- 60,000
- 80,000
- 100,000
- 120,000
- 140,000
- 160,000

Fatalities per 100,000 persons:
- 0
- 2
- 4
- 6
- 8
- 10
- 12
- 14

- 5% per year increase
- 8% increase after 2010
Road Safety Policy Models

Intuitive model

(penalties, education, driver training, licensing)

Vehicle centric model

(vehicle standards for occupants, road standards vehicles),

Human Centric model

(road design, city planning for Limitations of the road users)
Systems Approach

• Structural analysis of injury producing systems

• Focus is on the injury causing properties of systems rather on the errors of owners, designers, operators.

• Moving away from conventional explanations which are myopic overlooking the interrelationships between the various components of the system.
“The zero vision is based on the notion of "allowing" incidents to occur, but at a level of violence that does not threaten life or long-term health.”

“In the zero vision, the entire transport system must be designed to accommodate the individual who has the worst protection and the lowest tolerance of violence.”

“The responsibility for every death or loss of health in the road transport system rests with the person responsible for the design of that system. This is the ethical basis for realizing the zero vision.”

CLAES TINGVALL
Key Principles of Safe System Approach (SSA)

• Principle 1: Recognition of human fraility
• Principle 2: Acceptance of human error
• Principle 3: Creation of a Forgiving environment and appropriate crash energy management.

Thus design of roads play an important role in road safety and improved geometric design of road infrastructure could in turn improve road safety.
Sustainable safe traffic system

a road environment with an infrastructure adapted to the limitations of the road user;

vehicles equipped with technology to simplify the driving task and provided with features that protect vulnerable and other road users; and

road users that are well informed and adequately educated.
SAFE SYSTEM APPROACH

- Admittance to system
- Understanding crashes and risks

Alert and compliant road users

- Safer speeds (lower speeds more forgiving of human error)
- Human tolerance

- Safer vehicles
- Safer roads and roadides (more forgiving of human error)

- Enforcement of road rules

- Education and information supporting road users

- Safer travel

Speed management by design
Forgiving roads/streets
Discussion on a paradigm shift

Emphasis on driver’s fault ~ 78%-80% is not important

Road user behavior can be influenced by change in road and vehicle design and law enforcement.
Pillars of the Plan (different effectiveness)

- Road safety management
- Safer roads and mobility
- Safer vehicles
- Safer road users
- Post-crash response
Road Safety Theories (Elvik, 2004)

• Engineering Effect
• Behavioural Adaptation

• Improved lighting: Improves visibility - Engineering effect
• Road users tend to be less alert - behavioural adaptation
Impact angle, Kinetic energy and travel speed
Roundabout safety

- Roundabout:
  - 8 Vehicle conflicts
  - 8 Pedestrian conflicts

- Intersection:
  - 32 Vehicle conflicts
  - 24 Pedestrian conflicts
Measures to enhance road safety

- Speed control
- Containment
- Protection from road side hazards
- Information through markings, signage
- Traffic Management
Speed and Safety

• Driving speed, is one of the behaviors affected by the driver’s perception of the road’s safety, and it is not necessarily compatible with the road’s design speed (Misaghi and Hassan, 2005).

• If a road design is very forgiving – i.e., wide shoulders, wide lanes, and no curves – the drivers’ confidence will rise and they will compensate by speeding (Shinar, 2007).

• If the speed chosen is not appropriate in a given situation, it may result in lose control and run-off-road accidents (Janssen et al., 2006).
**Design Speed and Speed limit (Geometry)**

- Design speed for lanes *depends on terrain type and Landuse*.

**Table 1-2 Design speed for 2,4,&6 lane highway**

<table>
<thead>
<tr>
<th>Nature of Terrain</th>
<th>Cross slope and the ground</th>
<th>Design speed (km/hr.)</th>
<th>Ruling</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain and Rolling</td>
<td>Up to 25 percent</td>
<td>100</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Mountainous and Steep</td>
<td>More than 25 percent</td>
<td>60</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4-2 Design Speed for Expressway**

<table>
<thead>
<tr>
<th>Nature of Terrain</th>
<th>Cross Slope of the Ground</th>
<th>Design Speed (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain</td>
<td>Less than 10 percent</td>
<td>120</td>
</tr>
<tr>
<td>Rolling</td>
<td>Between 10 and 25 percent</td>
<td>100</td>
</tr>
</tbody>
</table>

100 Expressway
80 divided 6/4 lane
60 Undivided
40 through settlement
Speed management by Design (IRC 99, 2018)

Note:
Both extremities of vulnerable reach shall be provided with speed breaker at location where it is really required to curtail the speed physically and the both extremities shall be provided with bar marking at other locations to serve as soft treatment.
Forgiving Highways: Clear Zone

- **Clear zone:**
  “unobstructed traversable area provided beyond the edge of the through carriageway for the recovery of errant vehicles.”

- Design speed of 110 to 120 kmph a **clear zone** width of 9 to 11m has been recommended.

- **Crash barrier** is to be provided in case it is not possible to provide the suggested clear-zone distance from the edge of carriageway.

Figure 5-1 Clear Zone
Guard Rails/Crash Barriers

Semi rigid (installation details: Height, base, are important)

Flexible (space for deflection is important)
“In general barrier curbs are not desirable for use on freeways and other high speed roadways. An out of control vehicle may over turn or become airborne as a result of impacting the curb. Curbs are not adequate to prevent a vehicle from leaving the roadway. Curbs are not suitable use in front of traffic barriers because they can result in unpredictable post-impact trajectories” (AASHTO, 1994)

“Currently, median barrier is recommended on all access-controlled, multilane highways with posted speeds greater than 70km/h if the median is less than 15 m wide” (Graham, J.L. et al., 2014)
Audible markers for shoulder marking

Reduction in run-off-the road crashes, demarcation of shoulders (FHWA, 2011)
Raised Edgeline Markings

Raised profile edge line markings
Traffic Sings Manual, Chapter 5:Road Markings, Page no. 21
Clause 4.39 to 4.48

4.39 Raised profile lines are prescribed for use as an alternative to the edge of carriageway marking to diagram 1012.1. They consist of a continuous line marking with ribs across the line at regular intervals (see figure 4-9). The vertical edges of the raised ribs stand clear of the water film in wet conditions, improving retroreflective performance under headlight illumination. The ribs also provide an audible vibratory warning to drivers should they stray from the carriageway and run onto the marking.

Diagram 1012.3. The 500 mm spacing is suitable for most edge lines laid on the main carriageway. On motorways, the 250 mm spacing is recommended for use on slip roads. The closer spacing helps to maintain the rumble effect, offsetting the likely lower speed. Closer spacing is not used on all-purpose

Diagram 1012.2
(for use on motorways)
Repeat information: Distance Markers at exit

Countdown markers at exit from expressway: Each bar represents a distance of 100 m
RoadsideHazards

Roadside hazard

Crashes occur in both urban and rural areas but are mostly a problem on rural roads.
Common methods for treating roadside safety issues (European guidelines)
Wrong median-raised and fencing
Wrong location of sign posts
Crash Barriers

- Steel W beam is present throughout the length of the road.
- Posts are embedded in concrete base
- The measured height is between 0.55m to 0.70m.
- Retro-reflective marking is missing on the guardrail.
- Distance from carriageway edge is 7.5m and distance from hazard is 1.5m
Crash Barriers

- No transition treatment for the guardrails
Urban Safety: 
Transport Infrastructure Design Principles

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Safe traffic system principles

a road environment with an infrastructure adapted to the limitations of the road user;

vehicles equipped with technology to simplify the driving task and provided with features that protect vulnerable and other road users; and

road users that are well informed and adequately educated.
Guiding Principles

• Space Allocation for different road users (pedestrians, bicycles, public transport, cars)
  – Separation vs integration
  – Crossing / intersections

• Speed management by design
  – Traffic calming
Guiding Principles

• Road geometric standards from Buses/VRUs (pedestrians, bicyclists, public transport users) perspective
• Traffic management policies that enable safe mobility of VRUs
• Road side vendors/ informal sector to be viewed as service providers
Main roads (arterial) are usually 20-25% of the total network (speeds 50-70km/h).
Road Typology

<table>
<thead>
<tr>
<th>Road Typology</th>
<th>Right of Way-ROW (m)</th>
<th>Design speed (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial Roads</td>
<td>50-80</td>
<td>50</td>
</tr>
<tr>
<td>Sub Arterial Roads</td>
<td>30-50</td>
<td>50</td>
</tr>
<tr>
<td>Collector Roads</td>
<td>12 - 30</td>
<td>30</td>
</tr>
<tr>
<td>Access Streets</td>
<td>6 - 15</td>
<td>15</td>
</tr>
</tbody>
</table>

...different roads are to be designed differently
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<tr>
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<td>6 - 15</td>
<td>15</td>
</tr>
</tbody>
</table>

...different roads are to be designed differently
The history of design speed mentioned in the various codes and journal publications over the years (1936-2003) is given in Annexure 1 of the Urban roads – codes of practice. The following three conclusions which clearly shows that there is a need to Re-think about the Design Speed vs. operating speed, especially in urban areas.

The new Standards like ASVV (CROW Manual-1998) and NCHRP Report (2003) recommend the following

1. **Wider lane widths (3.5m+) do not have co relation with low crash rates.**
2. **Operating speed and driver’s behavior (speeding) are related and influenced by lane widths. (Wider lane encourage high speed)**
3. **In urban areas there should not be difference in operating speed and design speed as the geometric features are based on design speed; it can confuse the driver and encourage higher speeds.**

### Objective Speed & Carriageway Width for two way traffic and with a high quality public transport network

<table>
<thead>
<tr>
<th>Objective Speed (km/h)</th>
<th>Desired Carriageway width (m)</th>
<th>Minimum Carriageway width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-70</td>
<td>7.7</td>
<td>7.5</td>
</tr>
<tr>
<td>50</td>
<td>7.3</td>
<td>7.1</td>
</tr>
<tr>
<td>30</td>
<td>6.9</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Note: The sizes stated in the table should be realized between the curbs are between the carriageway markings.

### Objective Speed & Carriageway Width for one way traffic and with a high quality public transport network

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</thead>
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<td>50-70</td>
<td>3.6</td>
<td>3.5</td>
</tr>
<tr>
<td>50</td>
<td>3.5</td>
<td>3.3</td>
</tr>
<tr>
<td>30</td>
<td>3.3</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Note: The sizes stated in the table should be realized between the curbs are between the carriageway markings.

Source: ASVV - Recommendations for traffic provisions in built up areas, Record 15

<table>
<thead>
<tr>
<th>Speed Terms</th>
<th>Two lanes</th>
<th>Multilane Arterial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anticipated Operating Speed (mph)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anticipated Posted Speed (mph)</td>
<td>30</td>
<td>30-45</td>
</tr>
<tr>
<td>Design Speed (mph)</td>
<td>30</td>
<td>35-50</td>
</tr>
</tbody>
</table>
Cross section – Examples

Cross Section (45 m ROW)

CARRIAGEWAY
(raised (slope 1:30) top achieve clear height of minimum 2.75 m)

RAMPS (Slope 1:20)
TO ACCESS SUBWAY @ - 1500 mm M

SUBWAY

Cross Section – Half Subway
### Distribution of Road widths as per Priority

<table>
<thead>
<tr>
<th>ROW</th>
<th>Pedestrian</th>
<th>Cycle lane</th>
<th>Track</th>
<th>Service Lane</th>
<th>Green</th>
<th>Segregated Bus Lane</th>
<th>Parking</th>
</tr>
</thead>
<tbody>
<tr>
<td>6M - 12M</td>
<td>Red</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12M - 18M</td>
<td></td>
<td>Red</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18M - 24m</td>
<td>Red</td>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24m onwards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32m onwards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45m onwards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Red</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type of Road</td>
<td>ROW (m)</td>
<td>Bus lane</td>
<td>Lane (width)- One lane in each direction</td>
<td>Lane width- two lanes in each direction</td>
<td>Remaining Lane widths</td>
<td>footpath (on each side)</td>
<td>Green and Parking</td>
</tr>
<tr>
<td>-------------</td>
<td>--------</td>
<td>----------</td>
<td>------------------------------------------</td>
<td>-----------------------------------------</td>
<td>---------------------</td>
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<td>-------------------</td>
</tr>
<tr>
<td>Access: speed - 15 km/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>Nil</td>
</tr>
<tr>
<td>7</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>1</td>
<td>0.5 Nil</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>8</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>2</td>
<td>nil</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>9</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>3</td>
<td>1.5 Nil</td>
<td>nil</td>
<td>Nil</td>
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<td>10</td>
<td>nil</td>
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<td>nil</td>
<td>Nil</td>
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<td>11</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>5</td>
<td>2 (on one side)</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>12</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>6</td>
<td>2.5 (on one side with intermediate parking bays)</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>13</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>7</td>
<td>2.5 (on one side with intermediate parking bays)</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>14</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>8</td>
<td>2.5 (on one side with intermediate parking bays)</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>15</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>9</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>16</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>10</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>17</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>11</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>nil</td>
<td>Nil</td>
</tr>
<tr>
<td>18</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>12</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>1.5 m painted</td>
<td>nil</td>
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<tr>
<td>19</td>
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<td>20</td>
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<td></td>
<td>14</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>2.5 m segregated</td>
<td>nil</td>
</tr>
<tr>
<td>21</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>15</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>2.5 m segregated</td>
<td>nil</td>
</tr>
<tr>
<td>22</td>
<td>nil</td>
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<td>16</td>
<td>2.5 (on both side with intermediate parking bays)</td>
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<td>nil</td>
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<tr>
<td>23</td>
<td>nil</td>
<td>3</td>
<td></td>
<td>17</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>3 m segregated</td>
<td>nil</td>
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<tr>
<td>24</td>
<td>painted</td>
<td>3</td>
<td>3</td>
<td>12</td>
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<td>2 m segregated</td>
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<td>3.1</td>
<td>12.6</td>
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<td>2.3 m segregated</td>
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<tr>
<td>26</td>
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<td>3.1</td>
<td>3.1</td>
<td>13.6</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>2.3 m segregated</td>
<td>nil</td>
</tr>
<tr>
<td>27</td>
<td>painted</td>
<td>3.1</td>
<td>3.1</td>
<td>14.6</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>2.3 m segregated</td>
<td>nil</td>
</tr>
<tr>
<td>28</td>
<td>painted</td>
<td>3.1</td>
<td>3.1</td>
<td>15.6</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>3 m segregated</td>
<td>nil</td>
</tr>
<tr>
<td>29</td>
<td>painted</td>
<td>3.1</td>
<td>3.1</td>
<td>16.6</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>3 m segregated</td>
<td>nil</td>
</tr>
<tr>
<td>30</td>
<td>painted</td>
<td>3.1</td>
<td>3.1</td>
<td>17.6</td>
<td>2.5 (on both side with intermediate parking bays)</td>
<td>3.5 m segregated</td>
<td>nil</td>
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<tr>
<td>Distibutory: Speed - 30 km/hr</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Highway passing through the city
Highway passing through the city
Main Arterial Roads
30m and above ROW
Collector Roads
15m and above ROW

Access Roads
15m and above ROW
Intersection Design

- Intersection control conflicting and merging traffic.

- Three main types – signalized, unsignalized and roundabouts.

- Grade separated facilities are not desirable within urban limits and accessibility due to their adverse impact on accidents, pollution etc.

- Grade separated facilities divide urban landscape into separate zones, making pedestrians and cyclists extremely vulnerable.
Safe Intersection design Principles
( Candappa et al., 2015):

• **Principle 1 – key principle – limit travel speeds through intersections to 50 km/h** There is general acceptance that 90° collisions between two passenger vehicles involving impact speeds greater than 50 km/h are likely to exceed the biomechanical tolerance threshold of humans given current vehicle structures (Bostrom et al., 2008; Fildes et al., 1994; Tingvall and Haworth, 1999).

• **Principle 2 – important principle – avoid 90° impact angles** Fig. 1 presents the reduction in kinetic energy in the lateral direction that can be achieved through the manipulation of impact angle. For example, at 70 km/h, colliding at a 90° angle generates kinetic energy of around double the maximum tolerable lateral kinetic energy of 96.5 kJ. Halving this impact angle, similar to impact angles at roundabouts, reduces the lateral kinetic energy to the biomechanical threshold.

• **Travel speeds above 50 km/h, 90° impact angles are not compatible with Safe System ideals.** Impact speeds of up to 70 km/h were considered tolerable if 90° impact angles could be modified to more favourable angles (Corben et al., 2010). To aim for a Safe System intersection design then, optimising impact angles where possible is considered an “important” principle.
• Principle 3 – important principle – physically separate vulnerable road users or provide travel speeds <30 km/h. Vulnerable road users, defined here as pedestrians and twowheeler users (Australian Government Standing Committee on Planning Environment and Territory and Municipal Services, 2014; SWOV – Institute for Road Safety Research, 2012), are particularly affected by the potential levels of kinetic energy at intersections.

• The absence of any vehicle protection leaves vulnerable road users open to the full force of a crash. In fact, the safest means of ensuring Safe System compatibility with respect to vulnerable road users is to physically separate them from other road users.

• Temporal separation of vulnerable road users from vehicles is less effective in meeting Safe System ideals as this still relies on road user compliance and avoidance of error.

• For this reason, temporal separation has not been defined within Principle 4 as it still leaves open the possibility of serious injury.
• Intersections where the sight distance is poor have significantly higher injury and total accident rates. However, accidents may increase with sight distance on roundabout approaches.
• There is disagreement on the optimum angle of approach at intersections.
• Median widths should be as wide as practical at rural unsignalized intersections but not wider than necessary at signalized intersections.
• Channelization is usually beneficial but the construction of raised solid islands in the primary road may be hazardous in rural areas.
• The hazard of an at-grade intersection increases as the approach speed increases.
Location of Bus Shelter

Existing Scenario

Proposed Scenario

- Dedicated space for bus shelter leading to obstruction free cycle track and footpath
- Integration of amenities at junction for better visibility
- Bus Stop encroaches the pedestrian right of way.
- Presence of parking
- Presence of E-rickshaws
- Presence of cycle rickshaws
- Presence of hawker stalls
- Dedicated bays for E-rickshaws
- Table Top Crossings
- Shaded space of hawker stalls
- Rumble Strips before raised crossing
- Bus Stop Marking painted on the road
- Dedicated parking for Auto rickshaws
- Chhota Bazaar Chhota Bazaar
- Hanuman Chowk - Roundabout
- To Wezpura
- To Wezpura
Integration of Hawker Space
Roundabout

Junction Type: Arterial to Arterial
(Signalised Junction, free left turning)
Roundabout

Junction Type: Arterial to Arterial
(Roundabout with free left turn)

a: ROW
b: Inscribed circle dia.
c: Central island
d: Pedestrian refuge area
Non Signalized Intersection

Junction Type: Distributory to Access
(Non - Signalised Raised Junction)

a: distributory road (12m to 30m)
b: access road (6m to 15m)
c: raised junction crossing

a: distributory road (12m to 30m)
b: access road (6m to 15m)
c: raised crossing on every arm after turning
Safe pedestrian crossing
CODE OF PRACTICE FOR URBAN ROADS

Institute of Urban Transport, Delhi
WWW.IUTINDIA.ORG
Conclusion/way forward

........realization of vision zero also requires generation of new knowledge and establishing a process which enables generation of new knowledge to ensure safe highways in LMICs. Given the complexity of traffic safety science and its implementation in field, *continuous experimentation is required to develop safe highways based on the principles of safe systems approach.*