Highway Safety

Safety Audit & Safety in Work Zones

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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)
Accidental Elements & % age Contribution

Basic elements of road accidents are:

- Humans
- Vehicle
- Road

%Age Contribution in Road Accidents by these Elements

- Road: 54-62%
- Vehicle: 28-34%
- Humans: 8-12%
Principles of Road Safety

- Geometric Design (cross section, horizontal and vertical curves, sight distance, shoulder and median designs)
- Road surface characteristics
- Road markings and delineation
- Road signs, furniture
- Traffic management aspects relating to safety
- Road works and maintenance
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.
Injury Producing Systems

- Accident is a failure in a subsystem, or the system as a whole that damages one or more unit
Conflict between safety and mobility

- Higher level of service implies higher speeds-i.e. higher probability of fatality
Relation between Traffic Flow Density and Speed

If $M$ = Kilometers driven
$D$ = Density of number of cars in the system
$V$ = Speed

Then $M = D \cdot V$ \hspace{1cm} (1)

The number of accidents in the system ($U$) can be calculated by multiplying the traffic flow with the specific risk of the system ($u$), so we get

$U = u \cdot M = u \cdot D \cdot V$ \hspace{1cm} (2)
Analysis

This shows that the traffic safety can be increased by:

1. Reducing the specific accident risk in the system
2. Reducing the number of elements
3. Reducing the speed
Impact angle, Kinetic energy and travel speed
Roundabout safety

Roundabout:
- 8 Vehicle conflicts
- 8 Pedestrian conflicts

Intersection:
- 32 Vehicle conflicts
- 24 Pedestrian conflicts
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.
Discussion on a paradigm shift

MoRTH continues emphasis on driver’s fault ~ 78%

Based on police reports
SAFE SYSTEM APPROACH

- Admittance to system
- Understanding crashes and risks
- Education and information supporting road users
- Enforcement of road rules

Alert and compliant road users

- Safer speeds (lower speeds more forgiving of human error)
- Safer roads and road sides (more forgiving of human error)

- Human tolerance

Safer travel

Speed management by design
Forgiving roads/streets
Road traffic deaths in India 1970 though 2014
(Source: NCRB).

- ~10% underreporting total deaths 1,41000 (2014)
- Injury crashes underreported by 4 time
- Estimated serious injuries 20 times of fatalities
Fatalities per 100 thousand population

- TN, HP, HY, K, AP have high rates
- Uts have reduced rates
## Type of victims on fatal crashes on highways

<table>
<thead>
<tr>
<th>Location</th>
<th>Pedestrian</th>
<th>Bicycle</th>
<th>Motorised two-wheeler</th>
<th>Car</th>
<th>Bus</th>
<th>Truck</th>
<th>Unknown &amp; other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highways (1998)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>32</td>
<td>11</td>
<td>24</td>
<td>15</td>
<td>3</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>2lane NH8 (2010-2014)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>20</td>
<td>2</td>
<td>42</td>
<td>14</td>
<td>9</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>4lane NH24 (2010-2014)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>27</td>
<td>5</td>
<td>44</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>6lane NH1 (2010=2014)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>34</td>
<td>3</td>
<td>10</td>
<td>6</td>
<td>5</td>
<td>41</td>
<td>1</td>
</tr>
</tbody>
</table>

**Notes:** (1) Data from locations on 34 national and state highways in India (Tiwari, G. et al., 2000). (2) Tiwari, G., 2015
Type of vehicles involved in fatal crashes on highways

<table>
<thead>
<tr>
<th>Location</th>
<th>Truck</th>
<th>Bus</th>
<th>Car</th>
<th>TSR</th>
<th>MTW</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highways (1998)$^1$</td>
<td>65</td>
<td>16</td>
<td>15</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>2-lane NH8 (2010-2014)$^2$</td>
<td>47</td>
<td>5</td>
<td>17</td>
<td>1</td>
<td>5</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>4-lane NH24 (2010-2014)$^2$</td>
<td>54</td>
<td>8</td>
<td>9</td>
<td>4</td>
<td>3</td>
<td>22</td>
<td>100</td>
</tr>
<tr>
<td>6-lane NH1 (2010-2014)$^2$</td>
<td>72</td>
<td>3</td>
<td>12</td>
<td>1</td>
<td>2</td>
<td>10</td>
<td>100</td>
</tr>
</tbody>
</table>

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## Type of crash on highways

<table>
<thead>
<tr>
<th>Highway Type</th>
<th>Overturn</th>
<th>Head-on</th>
<th>Angle</th>
<th>Rear-end</th>
<th>Pedestrian and bicycle</th>
<th>Fixed object</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 lane with paved shoulder undivided</td>
<td>6</td>
<td>33</td>
<td>6</td>
<td>21</td>
<td>21</td>
<td>~</td>
<td>5</td>
</tr>
<tr>
<td>4 lane divided</td>
<td>0</td>
<td>6</td>
<td>2</td>
<td>54</td>
<td>32</td>
<td>~</td>
<td>1</td>
</tr>
<tr>
<td>6 lane divided</td>
<td>2</td>
<td>10</td>
<td>9</td>
<td>28</td>
<td>45</td>
<td>~</td>
<td>1</td>
</tr>
<tr>
<td>2 lane hill road</td>
<td>77*</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td></td>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>

*Run off vehicles 76% and 1% overturn*
Rural?

- Low density development
- Highway passing through small towns and villages
Rural Highway Development Issues

Guidelines for highway development generally follow international specifications and are not tailored to the country specific situations in the less motorised nations like:

– Presence of tractors, bicycles and other NMVs
– High density living pattern along the highways
– Bicycles and pedestrians not being conspicuous at night
– Truck drivers evolving peculiar behavior patterns to communicate with each other and other road users
– Road users avoiding traveling long distances to find gaps, and traveling in the wrong direction instead.
Rural Highway Design Issues

- Designed to carry motorized traffic at 60-120 km/h
- Geometric design to ensure m.v. safety:
  - Shoulder widths – runway zone/recovery zone
  - Central median and gaps. Distance between gaps
  - Separation for non-motorized vehicles
  - Traffic calming in semi-urban locations
  - Road crossing facilities for pedestrians and animals
Rural Highway Design Issues ....contd.

• Road-side furniture to ensure safety:
  – Crash barriers
  – Road markings and Signages
  – Wayside amenities and roadside trees

• Vehicle design issues to ensure safety:
  – Conspicuity of slow moving vehicles
  – Conspicuity of fronts and backs of trucks

• Guidelines for road safety audits
Rumble strips laid thicker than the specified 15-25mm (according to IRC 39 – 1986)
Car speed vs distance from speed breaker

Heavy vehicle speed

Speed of M2W
Design faults on newly constructed highways

Poorly Planned & Maintained Bus stand
raised median,
mixing of slow and fast traffic
Wrong median-raised and fencing
Safe highways - median, audible markers, crash barrier
Guard Rails
New Jersey Barriers
Shoulder rumble strips

Problem: Roadway departures account for more than half of all roadway fatalities.
Roadway departure fatalities, which include run-off-the road (ROR) and head-on fatalities, are a serious problem in the United States. In 2003, there were 25,562 roadway departure fatalities, accounting for 55 percent of all roadway fatalities in the United States. That same year, more than 16,700 people died in ROR crashes (39 percent of all roadway fatalities). In 2008, 304 persons were killed in noninterstate roadway departure crashes in New York State.

14% reduction in all ROR crashes after the installation of shoulder rumble strips
Safe Highway (Japan)
Roadside Hazards

About a third of motor vehicle deaths involve vehicles leaving the roadway and hitting fixed objects such as trees or utility poles alongside the road. Almost all such crashes involve only 1 vehicle. **Roadside hazard** crashes occur in both urban and rural areas but are mostly a problem on rural roads.
Case H1: $SSD < ASD_{hor} = MSD$

Case H2: $SSD < ASD_{hor} < MSD$

Case H3: $ASD_{hor} < SSD < MSD$

$MSD =$ Maximum distance that the driver can see an object placed on the road surface, assuming that no obstacle blocks driver’s line-of-sight;

$ASD_{hor} =$ Available distance that the driver can see an object placed on the road surface;

$SSD =$ Stopping sight distance;

$AC =$ Driver’s line-of-sight vector to $MSD$;

$AB =$ Driver’s line-of-sight vector to $SSD$;

$AD =$ Driver’s line-of-sight vector to $ASD_{hor}$;

$A =$ Driver’s current location;

$B =$ The end of $SSD$ measured along the roadway from driver’s current location;

$C =$ The farthest point that the driver can see from his current point, assuming that no obstacle blocks his or her line-of-sight;

$D =$ The actual point that the driver can see from his current point.

Note: all distances are measured along the roadway.

Fig. 3. Line-of-sight at horizontal curve sections.

$$SSD = 0.278Vt + \frac{V^2}{254\left(\frac{g}{9.81}\right) \pm G}$$
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).
Speed control Measures

• Lower speeds can be achieved by several passive measures such as speed limit signs, road markings and active measures such as speed bumps, roundabouts, and road surface (Martens et al., 1997).

• However, on well-designed highways, in terms of lane width, horizontal curvature, super elevation, drivers slow down voluntarily. In these cases, the traffic environment and road design are “self-explaining” (Theeuwes and Gosthelp, 1995).
Common methods for treating roadside safety issues (European guidelines)

1. Remove the obstacle
2. Redesign the obstacle
3. Relocate away
Common methods for treating roadside safety issues (European guidelines)

4. Reduce impact severity

5. Shield the obstacle

6. Delineate the obstacle
Work Zone fatalities - Globally

- **Netherlands**: 16% of total fatalities are on Dutch motorways of which 39% are in a Work Zone (SWOV 2005)
- **USA**: 3 times higher accident risk on workzones (www.workzonesafety.org/crash_data/workzone_fatalities)
- **INDIA**: Work zones accident statistics are not well documented. With increasing road construction activity in India, high risk of work zone fatalities
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Work Zone Fatalities - Globally

- **USA** - Annual work zone fatalities rose from 872 in 1999 to 1,028 in 2003 (FHWA, 2004)
- **Finland** - Work-related road crashes caused 28.5% of traffic deaths in Finland from 2001-2005
- **India** – Results of the Safety Audit done by IIT Delhi (2010) in work zones on NH-28

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Length (km)</th>
<th>Duration (month)</th>
<th>Fatal</th>
<th>Non-fatal</th>
<th>Fatal accident/month/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36.75</td>
<td>15</td>
<td>24</td>
<td>112</td>
<td>0.044</td>
</tr>
<tr>
<td>5</td>
<td>44</td>
<td>17</td>
<td>38</td>
<td>100</td>
<td>0.051</td>
</tr>
<tr>
<td>7</td>
<td>39.2</td>
<td>19</td>
<td>32</td>
<td>202</td>
<td>0.043</td>
</tr>
<tr>
<td>8</td>
<td>41.115</td>
<td>18</td>
<td>28</td>
<td>20</td>
<td>0.038</td>
</tr>
<tr>
<td>10</td>
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<td>19</td>
<td>22</td>
<td>38</td>
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<td>11</td>
<td>36</td>
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<td>26</td>
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<tr>
<td>12</td>
<td>40</td>
<td>18</td>
<td>11</td>
<td>59</td>
<td>0.015</td>
</tr>
</tbody>
</table>

- With increasing road construction activity (NHDP project) in India, high risk of work zone fatalities
Deaths and injuries at work zones are caused by a variety of factors (Lindly et al. 2002)

- speeding traffic
- inadequate visibility of signs
- poor road surface condition
- inadequate traffic control
- improper management of material
Work Zone Crashes review

- equipment, and personnel in work zones
- not paying attention to work zone signs or flaggers indicating slow down
- distraction by cellular phone calls, conversations and activities at roadside

➢ “Appropriate speed” at work zones has been identified by many researchers as one of the most important factors
What impacts Work Zone speeds?

• **Static signs were ineffective at reducing speeds** unless construction activity was in place (Bham et al., 2011).

• Speed limit signs are not only ineffective, they can make drivers skeptical of the validity of signs posted at other WZs in case of no construction activity in long WZs (Outcalt, 2009).
Work Zone Study (NH8), 2012

- To determine the speed characteristics of vehicles in Advance Warning Zone (AWZ), Working Zone (WZ) and Terminal Transition Zone (TTZ) before and after the installation of Active traffic calming measures like Rumble strips on NHs
- To estimate speed limit compliance in WZs using Active traffic calming measures in work zones
- To determine the effectiveness of different Warning sign configuration (shape and colour) in Work Zones
WORK ZONE ISSUES: Non-standard signs and barricades
Speed control by design
Mean speeds in Traffic Control Zones

Posted speed limit = 40 km/h

Mean Speed (km/h)

- Site 1
- Site 2
- Site 3
- Site 4

- Highest speeds by Cars followed by LCVs and Motorized 2-Wheelers
- No difference in speeds in Advance Warning, Working and Terminal Transition zones
Mean speeds in Traffic Control Zones

**Posted speed limit = 40 km/h**

- **Site 5**
  - Mean speeds: Advance Warning Zone - 64 km/h, Working Zone - 58 km/h, Terminal Transition Zone - 65 km/h
  - Categories: M2W, Car, LCV, Truck

- **Site 6**
  - Mean speeds: Advance Warning Zone - 68 km/h, Working Zone - 61 km/h, Terminal Transition Zone - 58 km/h
  - Categories: M2W, Car, LCV, Truck

- **Site 7**
  - Mean speeds: Advance Warning Zone - 59 km/h, Working Zone - 51 km/h, Terminal Transition Zone - 47 km/h
  - Categories: M2W, Car, LCV, Truck

- **Site 8**
  - Mean speeds: Advance Warning Zone - 60 km/h, Working Zone - 50 km/h, Terminal Transition Zone - 43 km/h
  - Categories: M2W, Car, LCV, Truck

- **Highest speeds by Cars followed by LCVs and Motorized 2-Wheelers**
- **No difference in speeds in Advance Warning, Working and Terminal Transition zones**
Conclusions & Recommendations

• Passive traffic calming measures like signages, road markings, cones, barricades, etc. implemented in work zones on NH-8 had no significant effect in reducing the speed of vehicles in WZs.

• Active Traffic calming devices show considerable potential for reducing speeds and improving work zone speed limit compliance.

• Impact of colour and shape may influence legibility of workzones.
Way forward

• Traffic calming in urban areas and on rural highways passing through villages - revise current standards
• Separate bicycle lanes on arterial roads and service lanes along highways - revise current standards
• Mandatory road safety audit and implementation of VRU standards
• Enforcement of speed control by design
What is a road safety audit?

- A systematic procedure to integrate road safety knowledge into road design or road improvement in order to reduce the risk to which road users are submitted.

- A formal evaluation carried out by independent authorities and trained experts.
Where and when should audits be performed?

- Both on urban and rural roads
- On road projects at successive stages:
  - planning
  - design
  - implementation
  - After

The earliest the audit is started, the easiest it will be to influence or bring changes to the project

- On existing infrastructures
Different methods for different applications

Audits performed on documents
Projects at the planning and the design stages

Audits performed on the road
Projects at the implementation and reception stages
Existing roads
What is needed for audits?

- A formalized procedure for data collection including a checklist
- Expertise to prepare the checklist
- Independence, expertise and training to perform the audit

(for background only): Road standards (if any), a history of the road construction and modifications
Building up the checklist (I): principles for risk prevention

- Adaptation of road design and features to vehicle dynamics and to pedestrian movements
- Error and conflict avoidance
- Facilitation of emergency manoeuvres and of recovery after loss of control
- Speed control
- Injury prevention (*forgiveness*)
Building up the checklist (II) : principles for risk prevention

- Adaptation of road design and features to vehicle dynamics and to pedestrian movements
  - horizontal alignment, superelevation
  - roadsides, space sharing
  - road surfacing
  - junction design
Building up the checklist (III) : principles for risk prevention

• Error and conflict avoidance
  • road *readability* (self-explaining roads)
  • visibility distance (day and night)
  • hazard warning
  • junction design
  • separation of motorized and non-motorized traffic or adaptation of design to mixed traffic
  • prevention of parking and animal crossing
Building up the checklist (IV): principles for risk prevention

- Facilitation of emergency and recovery manoeuvres
  - road surfacing
  - roadsides

- Speed control
  - Avoidance of the need for abrupt changes of speeds
  - Modulation of desired speeds according to traffic mix
  - Adaptation of road design and features to desired speeds of vehicles
The road characteristics to examine (I)

- On road sections
  - alignment
  - cross section (carriageway and shoulders)
    *homogeneity/discrepancies*
  - surfacing (carriageway and shoulders)
  - signing, marking, road lighting
  - occupation of roadsides
  - possibility of moving obstacles
The road characteristics to examine (II)

• At junctions: junction layout
  • junction design for vehicles and pedestrians
  • advanced signing, signing at junction, traffic lights, lighting
  • surfacing
BOOBY TRAPS
Wayside amenities on highways
Starting Point of Toll Road: Missing Signage's Plates
Inadequate Shoulder Length to Accommodate runoff vehicles, Embankment Height 2-3m
U Turn: Elevation Different Between the both carriageway 1-2m, No Storage Lane for Turning vehicles
90 degree entry road to National Highway without clear set back distance
Uncovered Side Drain and Electric Poles Adjacent to Road Edge
Poorly Planned & Maintained Bus stand and Bus Lay bye

Parked Vehicles in Bus Lay Bye
Road side hazards; clear recovery areas
Rumble strips laid thicker than the specified 15-25mm (according to IRC 39 – 1986)
Non-standard signs and barricades