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Road Infrastructure and Road Safety

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ABSTRACT

Roadway Factors, including roadway and roadside design elements, play an important role indetermining the risk of traffic accidents. Negative road engineering factors include those where aroad defect directly triggers a crash, where some element of the road environment misleads a roaduser and thereby creates human errors.In particular, the geometry of the road influences both thefrequency and severity of road crashes.In this regard, concepts such as the “Forgiving Road SideDesign” and the “Positive Guidance” approach need to be integrated into the engineering design ofroads to minimize the risk of road accidents.Tools such as the International Road AssessmentProgram (IRAP)’s road safety audits (“Star Rating” reports) can help countries to identify the riskfactorsinroaddesign.

I. INTRODUCTION

The road network has an effect on crash risk because it determines how road users perceivetheir environment.In this sense, the roadway provides instructions to the road users on what theyshould be doing. Negative road engineering factors include those where a road defect directly triggersa crash, where some element of the road environment misleads a road user and thereby createshumanerrors. A framework for relating the series of events in a road crash to the categories of crash-contributingfactorsistheHaddonMatrix.Accordingtothematrixdevelopedby Dr.WilliamHaddonJr.in1970,therearethreedifferenttypesoffactors thatcontribute to roadcrashes:

a) HumanFactors
b) Vehicle Factors
c) Roadway/Environment Factors.

Roadway Factors include roadway androadsidedesignelements.AccordingtotheHighwaySafetyManual(HSM)oftheAmericanAssociation of State Highway and Transportation Officials (AASHTO), three percent (3%) of road crashes are due to only roadway factors, but thirty four percent (34%) ofroadcrashesareacombination of roadway factors and other factors (Figure 1).Research also showed that road andenvironment factors were responsible for seventeen percent (17%) of total expressway crashes in theRepublicofKoreaduringtheyear2011.

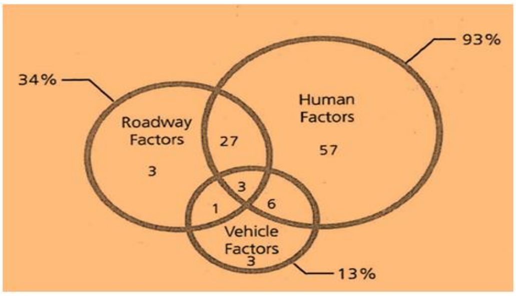


Figure1ContributingfactorstoVehicularCrashes(Source:AASHTO)

Safer roads and the mobility is one of the five pillars of the UN Global Plan for the Decade ofAction for Road Safety 2011-2020. The pillar emphasizes the need to raise the inherent safety andprotective quality of road networks for the benefit of all road users.This can be achieved throughmeasures including improved safety-conscious planning, design, construction and operation of roads.The activities under this pillar include encouraging governments to set a target to "eliminate high riskroads by 2020", identify hazardous road locations or sections where excessive numbers or severity ofcrashesoccurandtakecorrectivemeasuresaccordingly; andalsotopromotethedevelopmentofsafe new infrastructure that meets the mobility and access needs through use of independent roadsafety audit findings in the design and other phases of new road projects. One of the pillar activitiesalso emphasizes research and development in safer roads and mobility by completing and sharingresearchonthebusinesscaseforsaferroadinfrastructure.

II. ROAD PARAMETERS AFFECTING THE ROAD SAFETY

The geometry of the roadway plays a significant role in road crash frequencies as well as thecrash severity level. Different elements of the road design are important. However, a few parametersareconsideredtobemoreprominentandarediscussedbelow.

1. Cross-sectionoftheRoadway

Theverticalcrosssectionoftheroadwayparametersincludethewidthofthetravellane,widthandtypeoftheshoulder,andskidresistanceofthesurfaceofthetravelway.

The width of the travel lane does not only influence the comfort of driving and operationalcharacteristics of a roadway, but is also an important parameter affecting the road crash frequency aswell as crash severity.For any functional classification of roadway, whether it is an arterial road or alocal road, and for any environment of the roadway, whether it is an urban road or a rural road, whenthe lane width reduces, the probability of crashes increases drastically.For example, a study whichlooked at safety risks on a two-lane undivided highway, found that when the lane width was increasedfrom2.75meterto3.65meter,theprobabilityfor head-onorotherrelatedcrasheswasreducedbyfiftypercent(50%).

When the traffic volume is higher and the lane width is less, the probability for crashes,especially crashes like head-on or run-off the road, are greater. For example, in a multi-lane ruralhighwaywheretheaverageannualdailytrafficvolumeisgreaterthan2,000,theprobabilityforacrashonanarrowlanei.e.9feet(2.75meters) increasesbymorethanthirtypercent(30%).

A shoulder is the portion of the roadway contiguous with the travel lane that accommodatesstopped vehicles, emergency use etc. Generally, the shoulder width varies from 0.6 m to 3.6 m butthere are places where no shoulder can be accommodated.While it is desirable that a shoulder bewide enough for a vehicle to be driven completely off the travelled way, narrow shoulders are betterthan no shoulder at all.One study found that the probability for a road with a 60 cm wide shoulder oneach side, has thirty percent (30%) more crash risk than a road having a 1.8 metre wide shoulder oneachside.6

Regardless ofthewidth,ashouldershould be continuousand intermittent shouldersarebetter than no shoulders. The importance of wider shoulders is more acute in two-lane twoway roads.For a two-lane two-way road, if the daily average traffic volume is greater than 2,000, the probability ofcrashes for a very narrow width or no shoulder increases drastically, and if no shoulder is present thechanceofacrashincreasesbyfiftypercent(50%).

The shoulder type also governs the crash frequency. The shoulder material and thus thesurface condition have at least some impact on the recovery of an errant driver going out of the travellane. A paved shoulder is the best type of shoulder in terms of road safety and better than gravelshoulders. A gravel shoulder is better than a composite shoulder (combination of different types).However, a turf shoulder is considered to be the worst in terms of road safety and can lead to tenpercent(10%)morecrashes.

Literature shows that skidding crashes are a major concern in road safety. When the surfacefrictionisnotadequatetohelpstoppingavehicle,a vehiclegoesoutofcontrolandcrashesoccur.

Vertical and horizontal alignment, pavement types and texture affect a roadway’s skid resistance.Different pavement distresses or faults like rutting, polishing, bleeding and also dirty pavements causepoorskidresistancesofroadsurfaces.

2. Roadside Condition

The safety of the road does not depend only on the characteristics of the roadway but alsodependsontheconditionoftheroadside.Theterm“clearzone”isusedtodesignatetheunobstructed, traversable area provided beyond the edge of the travel way for the recovery of theerrantvehicle.Theclearzoneincludesshoulders,bicyclelanesandanyadditionalspace,ifavailable.

The greater the width of the clear zone, the more room is available for an errant driver torecover before hitting an object; thus, a greater clear zone means a safer road. In locations whererightofwayorthewidthavailableforprovidingclearareasisnotsufficient,itisnotpracticalorfeasible to consider the concept of clear zones as expected in general. This type of environment ismorecommonindenselypopulatedurbanareas.Consideringsafetyaspects,alateraloffsettoverticalobstructions(signs,utilitypolesetc.)isneededtoavoidcrashes.

The presence of a median is another important factor governing crashes, especially head-on-collisions.Most two-lane highways do not have median barriers to avoid capacity reduction of theroadway.However, median barriers are highly desirable in multi-lane highways in terms of safety andoperational efficiencies. Generally, the median width varies between 1.2 to 4 meters. The wider themedian, the better the safety situation is: Harkey et al conducted a study that revealed that amultilane divided highway with a 30 meter wide median has a four percent (4%) greater probability ofcrashes than a highway with a 9.0 meter wide median.7Even for urban arterial roads, one studyfound that conversion from an undivided urban arterial to one with a raised-curb median could result,onaverage,inatenpercent(10%)reductioninroadcrashes.

3. Curvature of the Roadway

Thehorizontalcurvature ofaroadwayisimportantbecause whena vehiclemovesin acircular path, it undergoes a centripetal acceleration that acts toward the centre of the curvature. Inother words, centrifugal forces try to move away the vehicle from its desired line of movement i.e thatis the curved roadway. The roadways at curves are provided with a geometric feature on the curvedportion of the roadway known as “super elevation”.In other words, the outer sides of the roadways atcurvesareelevatedwithrespecttotheinnerpart,sothata componentoftheself-weightofthevehiclehelpstopreventthevehicletomoveawayintheoutwarddirection.

However, the travel speed of the vehicle is also an important factor.If the travel speed of avehicle exceeds the suitable limit or design limit of the curve, then the vehicle loses control and aserious “out of control’ crash may take place. For example, on a curved portion of a two-lane highway,if the provided super-elevation is lower than two percent (2%) of the desired level, the probability ofroadcrashesincreasesbysixpercent(6%).

Transition curves are used between the straight part of the road and circular curves. Thistransition is provided through introducing spiral curves. If a transition curve is not properly provided,then centrifugal force will be applied to a vehicle all of a sudden, and depending on the speed andweight of the vehicle may translate into lack of control of the vehicle. Therefore, improper transitioncurveis moreriskyforheavierandfastmovingvehicles

The vertical grades or curvature of vertical curves of the roadways are also related to roadsafety.Whensteeperslopesareprovided,itbecomes moredifficultforavehicletobecontrolled.This is a more significant problem for heavier vehicles like trucks. A heavy truck faces difficulty inclimbing steep ascending grades, causing them to slow down.This in turn results in differentialspeeds among different types of vehicles. A two-lane highway located in steep terrain can have 15%more road crashes than a similar road located in a level terrain condition. Therefore, presence of aclimbing lane (additional lane) for heavier vehicles can reduce probability of crashes by 25% on a two-laneroadwaysection.

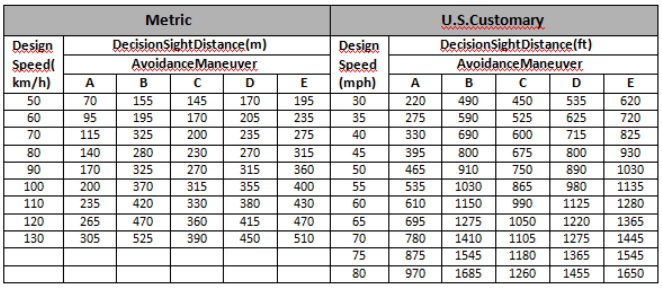
4. SightDistance

The alignment of the roadway has a great impact on road safety because a driver's ability tosee ahead is necessary for the safe operation of the vehicle and thus for the overall safety of thesystem. A sight distance of sufficient length is necessary so that a driver can control the operation oftheir vehicles to avoid hitting an unexpected object on the road. This is known as "Stopping SightDistance (SSD)". Another concept, of the sight distance is the "Passing Sight Distance (PSD)". For atwo-lane road where the speed is 60 kmph the SSD and PSD are 85 meters and 180 metersrespectively on level roadways. The passing sight distance is applicable to two-lane roads to enabledrivers to use the opposing traffic lane for passing (overtaking) other vehicles without interfering withoncomingvehicles.

While the concept of the SSD and the PSD are the prime importance in terms of road safety,the "Decision Sight Distance (DSD)" is another important topic to be addressed for the safety of theroad users. SSDs are sufficient for reasonably competent and alert drivers to come to hurried stopsunderordinarycircumstances,butgreater distancesareneededfordriversto takecomplexdecisions. The DSD is the distance needed for a driver to detect an unexpected or otherwise difficult toperceive information source or condition in a roadway environment; to recognize the conditions or itspotential threat; to select an appropriate speed and path; and to initiate and complete complexmaneuvers.10DSDprovidesdriversadditionalmarginsforerrorswheneverthereislikelihoodforerrors in information reception, decision making or taking actions by the drivers. The DSD variesdepending on the level of complexities and also on the road environment (e.g. urban, rural).Toaccommodate the variation in human capabilities in driving, a roadway is recommended to haveDecisionSightDistancesprovidedfordriversatalllocations.

Table 1, extracted from the AASHTO Green Book, shows the DSD for different levels ofcomplexitiesindifferentroadwayenvironments.

Table1DecisionSightDistance(DSD)



Metric						U.S.Customary					
Design Speed(km/h)	DecisionSightDistance(m)					Design Speed (mph)	DecisionSightDistance(ft)				
	AvoidanceManeuver						AvoidanceManeuver				
	A	B	C	D	E		A	B	C	D	E
50	70	155	145	170	195	30	220	490	450	535	620
60	95	195	170	205	235	35	275	590	525	625	720
70	115	325	200	235	275	40	330	690	600	715	825
80	140	280	230	270	315	45	395	800	675	800	930
90	170	325	270	315	360	50	465	910	750	890	1030
100	200	370	315	355	400	55	535	1030	865	980	1135
110	235	420	330	380	430	60	610	1150	990	1125	1280
120	265	470	360	415	470	65	695	1275	1050	1220	1365
130	305	525	390	450	510	70	780	1410	1105	1275	1445
						75	875	1545	1180	1365	1545
						80	970	1685	1260	1455	1650

AvoidanceManeuverA:Stoponruralroad 羊 t=3.0sAvoidanceManeuverB:Stoponruralroad 羊 t=9.1s

Avoidance Maneuver C: Speed/path/direction change on rural road ⺷ t varies between 10.2 and 11.2sAvoidanceManeuverD:Speed/path/directionchangeonsuburbanroad ⺷ tvariesbetween12.1and12.9sAvoidanceManeuverC:Speed/path/directionchangeonurbanroad ⺷ tvariesbetween14.0and14.5s
Source:TheAASHTOGreenBook

5. AccessManagement

Access management is the concept that access-related vehicular maneuvers and volumes canhave serious consequences on the performance of traffic operations and road safety. The benefits aresignificant, particularly in urban street environments where access points are numerous and trafficvolumesarehigh. Access management complements geometric design by reducing the likelihood of accessrelated vehicular conflicts or reducing the severity of the conflicts, by reducing the frequency of majorconflicts of movements. Generally, it can be expected that a doubling of access point frequency from10 to 20 per kilometer increases crash rates by roughly thirty percent (30%). Another doubling ofaccess frequency from 20 to 40 driveways per kilometer is expected to increase crash rates by sixtypercent(60%).Applicationsofaccessmanagementprinciplesalonetoexistingurbancorridorsgenerally results in reducing road crashes between 30 to 60 percent.11 In Malaysia, poor accesscontrolled or uncontrolled Federal Highways have much greater road crash rates than the well-controlledexpressways.

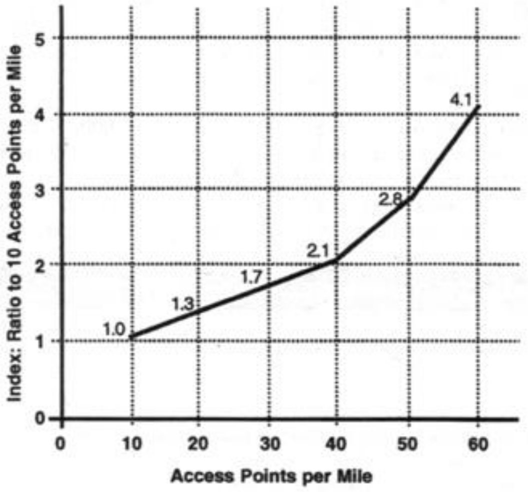


Figure2CompositeCrashRateIndices

Source:ITE(2008)UrbanStreetGeometricDesignHandbook

III. THE CONCEPT OF "FORGIVING ROAD SIDE DESIGN"

Roadwaysshouldbedesignedtoreducetheneedfordriver decisionsandtoreduceunexpected situations. The number of crashes increases with the number of decisions that need to bemade by the road user. Uniformity in highway design features and traffic control devices plays animportant role in reducing the number of required decisions, and by this means, the driver becomesawareofwhattoexpectonacertaintypeofhighway.

The concept of the "forgiving road side design" includes the provision for a clear recoveryarea. When a vehicle leaves the roadway in a crash, the driver no longer has the ability to fully controlthevehicle.Ingeneral,thismeans,whenadrivercommitsamistakeduetounavoidablecircumstances, his or her mistakes will be forgiven by the design concept. The concept of "forgivingroadside design" should not be independently applied to each design element but rather adopted as acomprehensiveapproachtohighwaydesign.12

IV. THE "POSITIVE GUIDANCE" APPROACHING ROAD DESIGN

Basic knowledge of human characteristics and limitations, and human reliance on expectationto compensate for those limitations in information processing, is important in road design. This led tothe development of the "positive guidance" approach in road design. Information processing demandsbeyond the drivers' capabilities overload and confuse drivers. A common characteristic of high riskroadlocationsisthattheyplacelargeorunusualdemandsovertheinformation-processingcapabilitiesofadriver. Therearelong-termandshort-termexpectationsdevelopedinthedriver'sminds.Forexample, a long-term expectation includes no Stop sign will be placed at an approach location on ahigh speed road; however, there are places where high speed roads do have Stop signs. Short-termexpectations include after negotiating a series of gentle slopes, the driver will find a sudden change inthetypeofslopes.

Knowledge of both engineering principles and the effects of human factors can be appliedthrough the positive guidance approach. The "positive guidance" approach means that road designthatisbasedonthedrivers'limitationsandexpectations,increasesthelikelihoodofdriversresponding to the situations as necessary thus preventing crashes. Potential driver behaviour can beanticipated in the road design process to assess the design and when trade-offs are appropriate,should be applied. Properly designed highways that provide positive guidance to drivers can operateatahighlevelofsafetyandefficiency.

V. SOME FINDINGS FROM THE INTERNATIONAL ROAD ASSESSMENT PROGRAM (IRAP)

International assessments have shown that in low and middle-income countries, reasonableinvestments for improving road geometry can be easily recovered through benefits from road crashsavings. One useful tool is the International Road Assessment Program, or iRAP.For example, oneiRAP report13 showed that widening of selected 40-km road sections in Bangladesh could prevent8,400 deaths with a benefit-cost ratio of five. Similarly, providing 270-km of motor cycle lanes inMalaysiacouldsave900liveswithabenefit-costratiooffifteen.

Starratingsareanobjectivemeasureofthelikelihoodofacrashoccurringanditsseverity.They draw on road safety inspection data and the extensive real-world relationships between roadcharacteristics and crash data. Thus, a methodology based on one to five (1-5) star ratings on thecrash risk of any given roadway developed by the International Road Assessment Program (iRAP)helpstopreventroadaccidentsthoughprioritizationofroadinfrastructureproactively.

The Karnataka State Highway Improvement Project (KSHIP) funded by the World Bank in India,set a good example of how road design can help to improve the road safety situation. The initial targetset was to have "three-stars" for the demonstration corridors. The process ultimately resulted in thedesign of better roads.These new designs were expected to result in fifty five percent (55%) fewerdeathsandseriousinjuries thanthebaselinecondition.

VI. CONCLUSIONS

"Road infrastructure" plays a vital role in road safety. Although a small proportion of crashes areexclusivelycausedbyroadwayfactors,asignificantnumberinvolveroadwayfactorsinsomeway.ThesecondpillaroftheUNGlobalPlanfortheDecadeofActionforRoadSafety2011-2020thusputsalotofemphasisonraisingthesafetyandprotectivequalityofroadnetworksforthebenefitofallroadusers.

Knowledge of roadway parameters affecting road safety can help to plan, design, build andmaintain the road infrastructure to facilitate a safe road environment. The design of roads plays amajor role in terms of road safety. The concept of "forgiving roadside design" should be applied andthe "positive guidance" approach should be adopted to reduce the road crash frequency and severity.International experiences show that interventions in terms of road infrastructure to improve the roadenvironmentcanpayforthemselvesandthefinancial investmentscanberecoveredwithinareasonableperiodoftime.

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