

ROAD INFRASTRUCTURE AND ROAD SAFETY

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ABSTRACT

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

INTRODUCTION

The road network has an effect on crash risk because it determines how road users perceive their environment. In this sense, the roadway provides instructions to the road users on what they should be doing. Negative road engineering factors include those where a road defect directly triggers a crash, where some element of the road environment misleads a road user and thereby creates human errors.¹

A framework for relating the series of events in a road crash to the categories of crash-contributing factors is the Haddon Matrix. According to the matrix developed by Dr. William Haddon Jr. in 1970, there are three different types of factors that contribute to road crashes: a) Human Factors b) Vehicle Factors and c) Roadway/Environment Factors.² Roadway Factors include roadway and roadside design elements. According to the Highway Safety Manual (HSM) of the American Association of State Highway and Transportation Officials (AASHTO), three percent (3%) of road crashes are due to only roadway factors, but thirty four percent (34%) of road crashes are a combination of roadway factors and other factors (Figure 1). Research also showed that road and environment factors were responsible for seventeen percent (17%) of total expressway crashes in the Republic of Korea during the year 2011.³

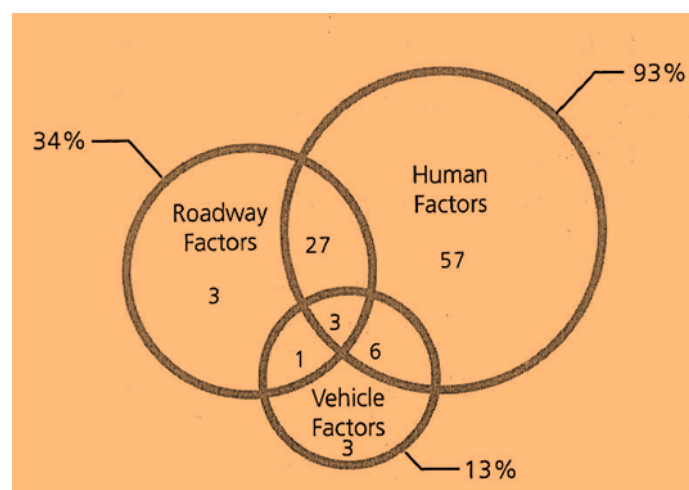


Figure 1 Contributing factors to Vehicular Crashes (Source: AASHTO)

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Safer roads and the mobility is one of the five pillars of the UN Global Plan for the Decade of Action for Road Safety 2011-2020. The pillar emphasizes the need to raise the inherent safety and protective quality of road networks for the benefit of all road users. This can be achieved through measures 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 risk roads by 2020”, identify hazardous road locations or sections where excessive numbers or severity of crashes occur and take corrective measures accordingly; and also to promote the development of safe new infrastructure that meets the mobility and access needs through use of independent road safety audit findings in the design and other phases of new road projects. One of the pillar activities also emphasizes research and development in safer roads and mobility by completing and sharing research on the business case for safer road infrastructure.⁴

I. ROAD PARAMETERS AFFECTING THE ROAD SAFETY

The geometry of the roadway plays a significant role in road crash frequencies as well as the crash severity level. Different elements of the road design are important. However, a few parameters are considered to be more prominent and are discussed below.

1.1 Cross-section of the Roadway

The vertical cross section of the roadway parameters include the width of the travel lane, width and type of the shoulder, and skid resistance of the surface of the travel way.

The width of the travel lane does not only influence the comfort of driving and operational characteristics of a roadway, but is also an important parameter affecting the road crash frequency as well as crash severity. For any functional classification of roadway, whether it is an arterial road or a local road, and for any environment of the roadway, whether it is an urban road or a rural road, when the lane width reduces, the probability of crashes increases drastically. For example, a study which looked at safety risks on a two-lane undivided highway, found that when the lane width was increased from 2.75 meter to 3.65 meter, the probability for head-on or other related crashes was reduced by fifty percent (50%).⁵

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 rural highway where the average annual daily traffic volume is greater than 2,000, the probability for a crash on a narrow lane i.e. 9 feet (2.75 meters) increases by more than thirty percent (30%).

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

Regardless of the width, a shoulder should be continuous and intermittent shoulders are better than no shoulders. The importance of wider shoulders is more acute in two-lane two way roads. For a two-lane two-way road, if the daily average traffic volume is greater than 2,000, the probability of crashes for a very narrow width or no shoulder increases drastically, and if no shoulder is present the chance of a crash increases by fifty percent (50%).

The shoulder type also governs the crash frequency. The shoulder material and thus the surface condition have at least some impact on the recovery of an errant driver going out of the travel lane. A paved shoulder is the best type of shoulder in terms of road safety and better than gravel shoulders. 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 ten percent (10%) more crashes.

Literature shows that skidding crashes are a major concern in road safety. When the surface friction is not adequate to help stopping a vehicle, a vehicle goes out of control and crashes occur.

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 cause poor skid resistances of road surfaces.

1.2 Roadside Condition

The safety of the road does not depend only on the characteristics of the roadway but also depends on the condition of the roadside. The term "clear zone" is used to designate the unobstructed, traversable area provided beyond the edge of the travel way for the recovery of the errant vehicle. The clear zone includes shoulders, bicycle lanes and any additional space, if available.

The greater the width of the clear zone, the more room is available for an errant driver to recover before hitting an object; thus a greater clear zone means a safer road. In locations where right of way or the width available for providing clear areas is not sufficient, it is not practical or feasible to consider the concept of clear zones as expected in general. This type of environment is more common in densely populated urban areas. Considering safety aspects, a lateral offset to vertical obstructions (signs, utility poles etc.) is needed to avoid crashes.

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 the roadway. However, median barriers are highly desirable in multi-lane highways in terms of safety and operational efficiencies. Generally, the median width varies between 1.2 to 4 meters. The wider the median, the better the safety situation is: Harkey et al conducted a study that revealed that a multilane divided highway with a 3.0 meter wide median has a four percent (4%) greater probability of crashes than a highway with a 9.0 meter wide median.⁷ Even for urban arterial roads, one study found that conversion from an undivided urban arterial to one with a raised-curb median could result, on average, in a ten percent (10%) reduction in road crashes.⁸

1.3 Curvature of the Roadway

The horizontal curvature of a roadway is important because when a vehicle moves in a circular path, it undergoes a centripetal acceleration that acts toward the centre of the curvature. In other words, centrifugal forces try to move away the vehicle from its desired line of movement i.e that is the curved roadway. The roadways at curves are provided with a geometric feature on the curved portion of the roadway known as "super elevation". In other words, the outer sides of the roadways at curves are elevated with respect to the inner part, so that a component of the self-weight of the vehicle helps to prevent the vehicle to move away in the outward direction.

However, the travel speed of the vehicle is also an important factor. If the travel speed of a vehicle exceeds the suitable limit or design limit of the curve, then the vehicle loses control and a serious "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 of road crashes increases by six percent (6%).⁹

Transition curves are used between the straight part of the road and circular curves. This transition 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 and weight of the vehicle may translate into lack of control of the vehicle. Therefore, improper transition curve is more risky for heavier and fast moving vehicles

The vertical grades or curvature of vertical curves of the roadways are also related to road safety. When steeper slopes are provided, it becomes more difficult for a vehicle to be controlled. This is a more significant problem for heavier vehicles like trucks. A heavy truck faces difficulty in climbing steep ascending grades, causing them to slow down. This in turn results in differential speeds 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 a climbing lane (additional lane) for heavier vehicles can reduce probability of crashes by 25% on a two-lane roadway section.

1.4 Sight Distance

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

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 the road users. SSDs are sufficient for reasonably competent and alert drivers to come to hurried stops under ordinary circumstances, but greater distances are needed for drivers to take complex decisions.

The DSD is the distance needed for a driver to detect an unexpected or otherwise difficult to perceive information source or condition in a roadway environment; to recognize the conditions or its potential threat; to select an appropriate speed and path; and to initiate and complete complex maneuvers.¹⁰ DSD provides drivers additional margins for errors whenever there is likelihood for errors in information reception, decision making or taking actions by the drivers. The DSD varies depending on the level of complexities and also on the road environment (e.g. urban, rural). To accommodate the variation in human capabilities in driving, a roadway is recommended to have Decision Sight Distances provided for drivers at all locations.

Table 1, extracted from the AASHTO Green Book, shows the DSD for different levels of complexities in different roadway environments.

Table 1 Decision Sight Distance (DSD)

Metric						U.S. Customary					
Design Speed (km/h)	Decision Sight Distance (m)					Design Speed (mph)	Decision Sight Distance (ft)				
	Avoidance Maneuver						Avoidance Maneuver				
	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

Avoidance Maneuver A: Stop on rural road— $t = 3.0s$

Avoidance Maneuver B: Stop on rural road — $t = 9.1s$

Avoidance Maneuver C: Speed/path/direction change on rural road— t varies between 10.2 and 11.2s

Avoidance Maneuver D: Speed/path/direction change on suburban road— t varies between 12.1 and 12.9s

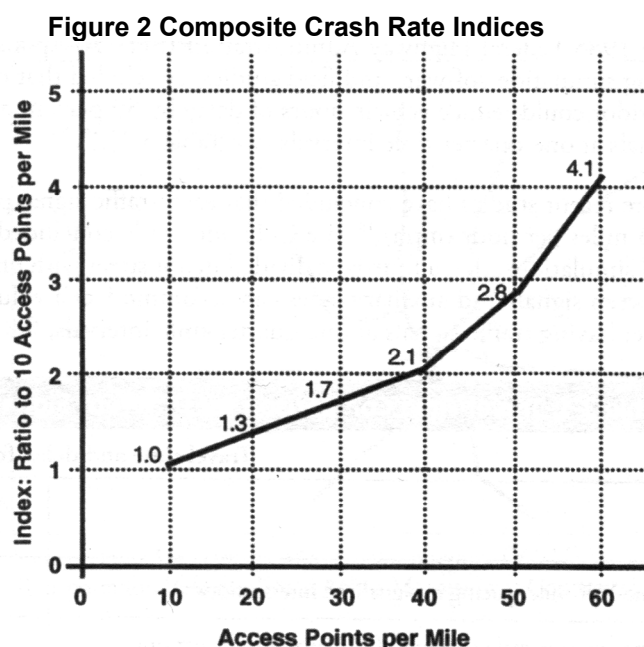
Avoidance Maneuver C: Speed/path/direction change on urban road— t varies between 14.0 and 14.5s

Source: The AASHTO Green Book

1.5 Access Management

Access management is the concept that access-related vehicular maneuvers and volumes can have serious consequences on the performance of traffic operations and road safety. The benefits are significant, particularly in urban street environments where access points are numerous and traffic volumes are high.

Access management complements geometric design by reducing the likelihood of access related vehicular conflicts or reducing the severity of the conflicts, by reducing the frequency of major conflicts of movements. Generally, it can be expected that a doubling of access point frequency from 10 to 20 per kilometer increases crash rates by roughly thirty percent (30%). Another doubling of access frequency from 20 to 40 driveways per kilometer is expected to increase crash rates by sixty percent (60%). Applications of access management principles alone to existing urban corridors generally results in reducing road crashes between 30 to 60 percent.¹¹ In Malaysia, poor access controlled or uncontrolled Federal Highways have much greater road crash rates than the well-controlled expressways.



Source: ITE (2008) *Urban Street Geometric Design Handbook*

II. THE CONCEPT OF “FORGIVING ROAD SIDE DESIGN”

Roadways should be designed to reduce the need for driver decisions and to reduce unexpected situations. The number of crashes increases with the number of decisions that need to be made by the road user. Uniformity in highway design features and traffic control devices plays an important role in reducing the number of required decisions, and by this means, the driver becomes aware of what to expect on a certain type of highway.

The concept of the “forgiving road side design” includes the provision for a clear recovery area. When a vehicle leaves the roadway in a crash, the driver no longer has the ability to fully control the vehicle. In general, this means, when a driver commits a mistake due to unavoidable circumstances, his or her mistakes will be forgiven by the design concept. The concept of “forgiving roadside design” should not be independently applied to each design element but rather adopted as a comprehensive approach to highway design.¹²

III. THE “POSITIVE GUIDANCE” APPROACH IN ROAD DESIGN

Basic knowledge of human characteristics and limitations, and human reliance on expectation to compensate for those limitations in information processing, is important in road design. This led to the development of the “positive guidance” approach in road design. Information processing demands beyond the drivers’ capabilities overload and confuse drivers. A common characteristic of high risk road locations is that they place large or unusual demands over the information-processing capabilities of a driver.

There are long-term and short-term expectations developed in the driver’s minds. For example, a long-term expectation includes no Stop sign will be placed at an approach location on a high speed road; however, there are places where high speed roads do have Stop signs. Short-term expectations include after negotiating a series of gentle slopes, the driver will find a sudden change in the type of slopes.

Knowledge of both engineering principles and the effects of human factors can be applied through the positive guidance approach. The “positive guidance” approach means that road design that is based on the drivers’ limitations and expectations, increases the likelihood of drivers responding to the situations as necessary thus preventing crashes. Potential driver behaviour can be anticipated 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 operate at a high level of safety and efficiency.

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

International assessments have shown that in low and middle-income countries, reasonable investments for improving road geometry can be easily recovered through benefits from road crash savings. One useful tool is the International Road Assessment Program, or iRAP. For example, one iRAP report¹³ showed that widening of selected 40-km road sections in Bangladesh could prevent 8,400 deaths with a benefit-cost ratio of five. Similarly, providing 270-km of motor cycle lanes in Malaysia could save 900 lives with a benefit-cost ratio of fifteen.

Star ratings are an objective measure of the likelihood of a crash occurring and its severity. They draw on road safety inspection data and the extensive real-world relationships between road characteristics and crash data. Thus, a methodology based on one to five (1-5) star ratings on the crash risk of any given roadway developed by the International Road Assessment Program (iRAP) helps to prevent road accidents through prioritization of road infrastructure proactively.

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 target set was to have “three-stars” for the demonstration corridors. The process ultimately resulted in the design of better roads. These new designs were expected to result in fifty five percent (55%) fewer deaths and serious injuries than the baseline condition.

V. CONCLUSIONS

“Road infrastructure” plays a vital role in road safety. Although a small proportion of crashes are exclusively caused by roadway factors, a significant number involve roadway factors in some way. The second pillar of the UN Global Plan for the Decade of Action for Road Safety 2011-2020 thus puts a lot of emphasis on raising the safety and protective quality of road networks for the benefit of all road users.

Knowledge of roadway parameters affecting road safety can help to plan, design, build and maintain the road infrastructure to facilitate a safe road environment. The design of roads plays a major role in terms of road safety. The concept of “forgiving roadside design” should be applied and the “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 road environment can pay for themselves and the financial investments can be recovered within a reasonable period of time.

ENDNOTES

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