THE INFLUENCE OF ROAD GEOMETRIC DESIGN ELEMENTS ON HIGHWAY SAFETY

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ABSTRACT

Road safety is an issue of prime importance in all motorized countries. The road accident results a serious social and economic problems. Studies focused on geometric design and safety aim to improve highway design and to eliminate hazardous locations. The effects of design elements such as horizontal and vertical curves, lane width, shoulder width, superelevation, median width, curve radius, sight distance, etc. on safety have been studied. The relationship between geometric design elements and accident rates is complex and not fully understood. Relatively little information is available on relationships between geometric design elements and accident rates. Although it has been clearly shown that very restrictive geometric elements such as very short sight distances or sharp horizontal curve result a considerably higher accident rates and that certain combinations of elements cause an unusually severe accident problem. In this paper, road geometric design elements and characteristics are taken into consideration, and explanations are given on how to which extent they affect highway safety. The relationship between safety and road geometric design are examined through results of studies made in different countries and it compares the results of studies in different countries and summarizes current international knowledge of relationship between safety and the principal non-intersection geometric design parameters. In general, there is broad international agreement on these relationships.

Key words: Highway Safety, Geometric Design, Traffic Accident

1. INTRODUCTION

Geometric design elements play an important role in defining the traffic operational efficiency of any roadway. Key geometric design elements that influence traffic operations include number and width of lanes, the presence and widths of shoulders and highway medians, and the horizontal and vertical alignment of the highway [1]. Generally speaking, any evaluation of road safety, such as in the driving dynamic field, has been conducted more or less qualitatively. It is safe to say, from a traffic safety point view, that no one is able to say with great certainty, or prove by measure or number, where traffic accidents could occur or where accident black spots could develop.
However, everyone agrees that there exists a relationship between traffic safety and geometric design consistency. By all means, alignment consistency represents a key issue in modern highway geometric design. A consistency alignment would allow most drivers to operate safety at their desired speed along the entire alignment. However, existing design speed-based alignment policies permit the selection of a design speed that is less than the desired speeds of majority of drivers [2]. Much of the research in highway safety has focused on different factors which affect roadway safety. The factors are categorized as traffic characteristics, road geometrics, road surface condition, weather and human factors. Previous research has shown that geometric design inconsistencies, operations (traffic mix, volume, and speed), environment, and driver behavior are the common causes of accidents. Most of the studies have shown the influence of various geometric design variables on the occurrence of accidents and have concluded that not all variables have the same level of influence in all places [3]. From the relation of factor mentioned above, different researchers have developed the relationship of roadway safety in terms of crash frequency and crash rates, fatality and injury rates and the road elements, traffic characteristics, and pavement conditions. Many of these previous studies investigated the relationship of crash rates or frequency in terms number of lanes, lane width, presence of median, median width, type of median, shoulder width, access density, speed limit, vertical grade, horizontal curvature, weather condition. The relationship between safety on the highway and factors mentioned above is the primary focus in crash reduction and predictions[3].

2. GEOMETRIC PARAMETERS AFFECTING ROAD SAFETY

An accident is always characterized by multiple causes. The alignment of road is an important influence factor: dimension of radii, ratio of consecutive curves, dimension of vertical curves and sight distance conditions. In many evaluation studies of safety effects of road design elements it turns out the present poor capacity to explain accidentality phenomenon; in fact the main causes of accident is behavior of driver, which is mainly influenced by his personality, skills, and experience. Furthermore external impacts like weather conditions, road conditions, time of day, or light conditions influence the driver behavior as well. It is out of question that analyzing accidents and their dependence on technical values or human factors has always to consider these interactions. The relation between accidents (all, property damage only, slight injuries, severe injuries, fatalities) and road geometry is proved but it is also a question of the driving behavior, especially of the velocity. Again and again investigations show that comparable curves (similar geometry) are characterized by different accident occurrence. One reason could be a different driving behavior: lower speeds are less critical than higher speeds in curves. Several studies, oriented to create relationships between accidentality and independent variables, were obtained in a particular context; so, in every other different conditions, weather conditions, user behavior, etc.) the influence of these factors should be considered, e.g. calibration procedure. Summarized, accidents do not depend on only one factor; accidents are caused rather by a combination of several factors [4].

3. THE RELATIONSHIP BETWEEN SPEED AND SAFETY

Speed is one of the major parameters in geometric design and safety is synonymous with accident studies [5]. For example, Finch et al. [6] recently concluded that a reduction of 1.6 km/hr (1 mph) in the average speed reduces the incidence of injuries by about 5%. Also it is generally accepted that there are substantial safety benefits from lower speed limits. For example, reducing rural speed limits from 100 km/hr to 90 km/hr has been predicted to reduce casualties by about 11% [7]. It is interesting to note that the relationship between the design speed and the speed limit is not referred to in the geometric design standards of many countries [8].
4. EFFECTS OF CHARACTERISTICS OF ROAD GEOMETRICAL DESIGN ELEMENTS ON TRAFFIC ACCIDENTS

Some of the primary geometric design elements that can affect on highway safety are carriageway, grade, horizontal curvature, shoulder, median, vertical curve [9]. The relationship between some characteristics of these elements and traffic accidents, including studies made in different countries are classified into groups: Cross-section effects and Alignment effects.

4.1 Cross-Section Effects

The widths of the various cross section elements affect the capability of driver to perform evasive maneuvers and determine the lateral clearances both between vehicles and between vehicles and other road users [5]. In the existing literature are mentioned especially the following parameters:

4.1.1 Lane Width

Wider lanes are traditionally associated with higher operating speeds and increased safety. The Highway Capacity Manual (HCM) documents that wider lanes for multilane highways result in higher free-flow speeds [10]. On the other hand, very little has been found on the safety implications of wider lanes. It is reasonable to assume that wider lanes may provide additional space to the driver to correct potential mistakes and thus avoid crashes. However, a driver could be expected to adapt to the available space, and the positive safety effects from the wider lanes may be offset by the higher speeds [10]. Generally, most studies agree that lower accident rates are attributed to wider lanes. But it seems that there is an optimal lane width around 3.5m. Studies have also noted that approaches should base on more parameters of the cross section, at least also on traffic volume [4]. However, Hearne's results [11] suggested that there was a marginal increase in accident occurrence with an increase in carriageway width. Hedman [12] noted that some results indicated a rather steep decrease in accidents with increased width of 4m to 7m, but that little additional benefit is gained by widening the carriageway beyond 7m. Zeger [13], Zeger/Council [14], and Mclean [15] have shown that width of 3.4–3.7m show the lowest accident rates. This is supported by the NCHRP Report 197 [16] conclusion that there is little difference between the accident rate for 3.35m and a 3.65m lane width. However, studies on low volume rural roads indicate that accidents continue to reduce for widths greater than 3.65m, although at a lower rate [17]. TRB [18] pointed out lanes wider than 3.70m do not contribute to a higher safety because they may result in unsafe maneuvers such as over taking despite of oncoming traffic. Another reason is the higher speed on wider lanes which leads to more accidents. Yagar and VanAerdo [19] found that the passage of a vehicle requires a minimum lane width and that any additional width beyond this minimum allows one to drive faster and/or with a greater measure and perception of safety. For lane widths from 3.3m to 3.8m, they reported that the operating speed is decreased by approximately 5.7 km/hr for each 1m reduction in width of the road [5]. Lamm et al.[20] found a significant decline of accident rate up to 7.5m cross sections. Council/Stewart [21] analysed data of four US states to develop a prediction model for non-intersection and non-intersection related accidents. The results were statistically for two states only and indicate huge differences regarding the benefits of widening cross sections. In North Carolina widening the surface by 1m reduces accidents by 14%, in California by 34%. Elviketal. [22] also figured out a decline of accident cost rates if the cross section is widened by maximum 3m. Wider cross sections are not attributed by positive influence on road safety. All mentioned works have pointed out a decline of accident risk for wider cross sections. This positive trend is proved up to a certain lane width, wider cross sections are characterized by a lower safety benefit or even by increasing accident risk [4] (Figure (1)).
4.1.2 Number of Lanes

The number of lanes is another variable which has been discussed in detail by various researchers. Almost all studies do conclude that the higher the number of lanes, the higher the crash rate [3]. In their research, Noland, and Oh [23] found that increasing the number of lanes was associated with increasing traffic crashes. In another study, Abdel-Aty and Radwan [24] found that more lanes in urban roadway sections are associated with higher crash rates. Garber [25], considered flow per lane and found that there was an increase in the crash rate as the flow per lane increased. Evidence of the effect of the number of lanes can be seen when a study is done on the conversion of a two-way roadway to four or six lanes. With such studies, most have shown an increase in the crash rate [3].

4.1.3 Shoulder Width and Type

There are several purposes in providing shoulder along the highway; these include to accommodate stopped vehicles so that they do not encroach on the travel lane, to make maintenance work, to facilitate access by emergency vehicles and to protect the structural integrity of the pavement [3]. About the impact of shoulder width or shoulder in general there are various opinions in the literature several positive as well as negative aspects are discussed. As an obstacle free zone the shoulder gives drivers the possibility to regain control after losing control over the vehicle [4]. There is also evidence that wider shoulders may encourage higher operating speeds because they may communicate to the driver the presence of wider space for correcting errors. Finally, the number of lanes, lane width, and shoulder width are interrelated, and the choice of geometric value for each of these elements typically affects the other elements [10]. The effect of shoulder width and type has been pointed out by different studies as an important aspect in crash frequency. The effect of shoulder width and shoulder paving material goes hand-in-hand with lane width, and road side events [3]. The study of Zegeer [13] has shown that increasing the shoulder width is associated with a decline of accidents. 21% reduction of total accidents was determined on road with shoulders of 0.9m-2.7m compared to road without shoulders. They suggested that for roads without shoulders the optimum shoulder width is about 1.5m. An investigation by Turner et al. [26] has shown that on 2-lane roads with paved shoulders and still higher than on 4-lane roads without shoulder. Similar results were worked out by Hedman [12] who found an accident reduction when shoulder increases up to 2m, above 2m the benefit became less. For 2-lane roads a reduction of accidents by 1% □ 3% and of injuries of 2% – 4% when the shoulder is widened by one foot [4]. Miaou [27] indicates a reduction of signal-vehicle accidents by 8.8% related to one foot widening. In general the design of shoulders regarding the pavement and width has positive influence on road safety. These effects were shown in numerous research works over the last years. A like the road width the positive effect becomes smaller up to a certain shoulder width. Wider shoulders have no positive impact. Also paved shoulders influence positively safety especially on narrow roads [4].

4.1.4 Median Width and Type

The most important objective for the presence of medians is traffic separation. Additional benefits from medians include the provision of recovery areas for errant maneuvers, accommodation of left-turn movements, and the provision for emergency stopping. Median design issues typically address the presence of median, along with its type and width [10]. One study which evaluated median types found that the safety of the median type decreased in the following order: flush unpaved, raised curb, crossover resistance, TWLTL [28]. Wider medians also seem superior to narrow medians plus a physical barrier, since these can only be effective if vehicles actually collide with them. Another study [29] found that type of median and nature of land use affect crash rate significantly. Srinivasan [30] found that on high-speed roads with two or more lanes in each direction, medians improve safety in a number of ways, for example by reducing the number of
head-on collisions. The Danish design standards [31] which was showed the relationship between the median width, the accident frequency of through section and a severity index for medians with and without a crash barrier, medians, particularly with barriers, reduce the severity of accidents, but medians wider than 3m show little additional benefit. In contrast, United States studies show continuing reductions in the number of injury crashes for widths up to 12m and over [17].

4.1.5 Climbing Lanes

A climbing lane is an extra lane in the upgrade direction for use by heavy vehicles whose speeds are significantly reduced by the grade. The increasing rate of crashes directly associated with the reduction in speed of heavy vehicles on steep sections of two-lane highway [32]. Hedman [12] quotes a Swedish study which concluded that climbing lanes on rural two-lane roads reduced the total accident rate by an average of 25%, 10% to 20% on moderate up gradients (3% to 4%) and 20% to 40% on steeper gradients. It was also observed that additional accident reduction can be obtained within a distance of about 1km beyond the climbing lane [5]. In earlier studies, Jorgensen [33] found no change in accident experience in the United States due to provision of climbing lanes while Martin and Voorhees [34] found a 13% reduction in accidents in the UK.

4.1.6 Access Density

Access density refers mainly to the number of driveways within a roadway segment. Access density is one of the factors which has been pointed out as the determinant of accident rates on the highways. One study done in New Jersey [35] on the impact of access driveways on accident rates for multilane highways found that approximately 30% of the reported crashes were in mid-block sections and were caused by the presence of access points. Another finding in this study was that approximately 25% of the entering/existing vehicles from/to access points have impact on mainline traffic. Karlaftis et al. [36] found that for rural multilane roads, median with and access control were the most important factors followed by the influence of pavement conditions in the crash. Some empirical evidence suggests that the accident rate increases linearly with access density, but some find that the increase is more than linear. The model developed by Gluck et al. [37] suggests that an increase from 10 access points to 20 access points per mile would increase crash rates by roughly 30%. Papayannoulis et al. [38] related traffic safety to access spacing, and presented results from eight states. They found that most literatures show an increase in accidents as a result of the increase in number of driveways. The study suggested that a road with 60 access points per mile would have triple the accident rate compared to 10 access point per mile.

4.1.7 Median Barrier

The literature review has identified conflicting results for the presence of median barriers [39]. Some have noted that the effectiveness of the presence of medians on safety cannot be conclusively identified but noted that there is potential for the median to impact safety [40]. Other have shown that median barriers have a positive effect, i.e. reduce crashes [21], and others have indicated that there is a relationship between median barriers presence and left shoulder width [41]. Another trend that was noted in the literature is the overall increase of crashes with median presence but a reduction of the level of severity for these crashes [42]. In general, the fact that an obstacle is placed within the roadway environment that provides a target for collisions can lead to an increased number of crashes [39]. The type of the median barrier is also an important aspect, since studies have shown that different types (especially concrete) have the potential to increase crashes [22]. The presence of a barrier will result in a reduction of cross-median type crashes but it also has the potential to increase median-related crashes, since its absence could allow drivers opportunities to stop their vehicles in the median [39]. Finally, the severity and type of the crash with and without the median barrier should be considered. Median barriers have the potential to reduce crossover crashes,
which often result in serious injuries. Therefore, the presence of the barrier has the potential to impact severity levels [39].

4.2 Alignment Effects

The alignment of a road can be described in very specific terms such as individual curves and gradient or in more general terms such as terrain types or topography [43].

4.2.1 Curve Radius

It is the main factor of radius for horizontal curve and it is obvious one for traffic accident. When the radius is smaller, the accident rate is higher. The transverse stability (includes slippage and overturn) happens before the longitudinal stability on the curve based on vehicle steering theory, so the radius value is decided by the transverse stability of vehicle [44]. The mean radius and degree of curvature for each category were computed and regressed against the natural logarithm of mean accident rate within each category. The results support previous results that the sharpness of curve is significant. The higher radius results from the grouping of sites and therefore, does not reflect the variability among individual sites. Table (1) shows the prediction model developed from a Swedish study on road with 90 km/hr speed limit [45].

Department of Transportation [46] include graphs which compared crash rates for horizontal curvature to a base crash rate by means of a multiplier which agree closely with the Swedish values shown in Table (1) the difference between straight sections and bends becomes significant at a radius of about 100 m. The UK data indicates continually increasing accident rate with reducing radius.

<table>
<thead>
<tr>
<th>Radius Curve From (m)</th>
<th>To (m)</th>
<th>500</th>
<th>700</th>
<th>1500</th>
</tr>
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<tbody>
<tr>
<td>300</td>
<td>0.25</td>
<td>0.35</td>
<td>0.45</td>
<td></td>
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<tr>
<td>500</td>
<td>–</td>
<td>0.10</td>
<td>0.30</td>
<td></td>
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<tr>
<td>700</td>
<td>–</td>
<td>–</td>
<td>0.20</td>
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</tbody>
</table>

This increase in crash rate becomes particularly apparent curve radii below 200 m. Simpson and Kerman [47] noted that low radius curves result in much shorter curve lengths and that the overall implications for accidents may not be as bad as would appear. It has been shown in past research that horizontal curves experience crash rate of up to four times the rates on tangent sections [48]. It has been shown by a number of researchers, Glennon et al. [49], Zegeer et al. [50], Glennon [51] that milder curves are associated with lower crash rates compared to sharper curves. For horizontal curves, casualty crashes seem to be more dominant than PDO (Property Damage Only) crashes. Those researchers also found that horizontal curves seem to have proportionately more head-on and opposite direction sideswipe crashes, fixed object, crashes, rollover crashes, and nighttime crashes compared to other sections [48]. Most investigations show that with increasing radii the accidents frequency declines [4]. Radii smaller 500 m [52] or 600 m [53] are associated with higher accident rates. Oecd [54] suggested radii smaller 430 m as critical. Due to driving dynamic aspects it is suggested that most accidents in curves are run off accidents. Leutzbach/Zoellmer found the accident rate as well as the accident cost rate decreases until radii of 1000 m. Great curves are again characterized by increasing accident rates and cost rates. These results confirm the investigation of Krebs/Klockner that the safety benefit becomes less in radii above 400 m [4]. In Glennon et al. [55] the curve degree is used as a parameter instead of the curve radius. Road segment of 1 km length, consisting of a curve and tangents of at least 200 m were investigated. All investigations have pointed out an important impact of the curve radius on road safety. In fact small radii are
characterized by a higher accident frequency as well as accident severity. The most typical accident type is the run-off accident. There are different opinions at which radius the impact decreases; it is discussed a range from 400 m to 600 m [4].

4.2.2 Curvature Change Rate
Various research projects have shown that the curvature rate (CCR) as value for consecutive elements correlates with safety relevant parameters. The CCR characterizes a combination of consecutive elements in spite of the radius which represents only a single element. The background is that identical radii could cause a different driving behavior and therefore a different accident risk [4]. Therefore, the CCR is a more appropriate value to describe the geometric properties of several elements. Pfundt and Babkov investigated the relation between the number of curves and the number of accidents. They found that roads with many curves are characterized by less accidents than roads with few curves [4]. Krebs/Klockner derived a correlation between the CCR and accident indicators the higher the CCR the higher the accident rate and accident cost rate. Hiersche et al. investigated roads with modern and historic alignment. Due to an increasing CCR they found a progressive incline of accident rate on historic alignments but a decline on roads with modern alignment. These results were also proved in Durth et al. [4]. Analogous to Hiersche they investigated modern and historic alignments. The results show that roads with similar CCR and continuous alignment are characterized by lower accident risk than roads with a discontinuous alignment. In general a higher CCR is associated with higher accident rates and cost rates [4]. Leutzbach/Zoellmer derived a slight increase of the accident rate related to the CCR. At CCR=100 gon/km the increase stops and the accident rate becomes lower while the CCR increases. They assume that two different effects are overlapping: on the one hand the number of accidents increases according to the traffic volume and on the other hand the average of accident severity decreases because the increasing CCR causes a lower speed. Due to the various accident types Leutzbach/Zoellmer [4] found that the number of driving accidents and accidents in longitudinal direction increase with CCR. This trend is also shown by the accident rate which increased twice. These results show a higher risk of driving accidents if the horizontal alignment is characterized by many curves. The study of Hammerschmidt investigated the relation between CCR and accident parameters on 500 km secondary rural roads. The results are showed that CCR about 150 gon/km–250 gon/km have high accident rates, CCR below 100 gon/km caused less than 25% accident costs and CCR above 250gon/km are characterized by a decline of accident cost rate again because of low speeds. In general it is proved the higher the CCR the higher the risk of an accident. Important is that with increasing CCR the severity of accidents decreases because of declining speeds. This is the main difference between road stretches of similar geometry (CCR=constant ) and single elements which discontinue the alignment [4].

4.2.3 Superelevation
In order to counteract some centrifugal force that acts on vehicle when it is running on the curve, usually the pavement traverse slope is designed as higher outside while lower inside to from single slope, this called superelevatin. This can counteract all or some centrifugal force and can improve traveling stability and comfort. The equation of traverse superelevation value (I) can be deduced by balance force act on vehicle when traveling on the horizontal curve as expressed:

\[ I = \frac{V^2}{127R} - U \]  

(1)

Where, each symbol meaning is above formula (1). When transverse slop is the range from 2% to 2.5% , the value (U) adopt (0.035), transverse slop is 2.5% , (U) adopt (0.040), transverse slope is 3% , (U) adopt (0.045), and so on [44].
Superelevation value can be calculated according design speed, radius value, road alignment, and considers local natural condition. Improper superelevation value or no superelevation all will cause accident [44]. Horizontal alignment and superelevation of curve have an impact on the traffic safety performance of highway sections. Research that relates traffic safety to roadway horizontal alignment has consistently shown that traffic accidents increase with increasingly sharper curve. Sharper curves in segments that otherwise have good alignment, tend to surprise drivers and create even more hazardous situations [48]. Consistency in design speeds along significant sections of highways has been advocated by some, as a means of controlling the incidence of surprise curves in other gentle alignments. However, design speeds for horizontal curves serve as function of the maximum superelevation policies adopted by a design agency. Therefore, a single curve design may be regarded as having different design speeds by agencies that have different maximum superelevation policies [56]. The superelevation of horizontal curves is used as an input variable in the Highway Safety Manual (HSM) methodology for rural two-lane highways. The HSM methodology considers the difference between the actual superelevation and the superelevation recommended by AASHTO policy. Superelevation affects safety in the HSM methodology only when this difference exceeds 0.01. Superelevation rates can be determined from existing data in computerized roadway inventory files, from as-built plans, or from field measurements Highway Safety Manual [57].

4.2.4 Transition Curve

The curvature of transition curve will proportional charge with the curve length, this can make the drivers turning steering wheels equably in some speed. When vehicle enters into circle curve from straight route in some speed or from circle curve to straight route of from one curve to another, its track is consistent with mathematic convolution curve, so it takes convolution curve as transition one [44]. The minimum length of transition curve should meet the follow expression:

$$L \geq \frac{V}{3.6} \cdot t$$  \hspace{1cm} (2)

Where:
- \(L\) = is the length of transition curve (m)
- \(V\) = is design speed (km/hr)
- \(t\) = is the shortest journey time on transition curve (sec) and is the adopted at least 3 seconds.

According to the characteristic of convolute curve, it can get the formula as follow:

$$C = rl = RLs$$

Where, \(C\) is the parameter of transition curve (m\(^2\)) which shows the change degree of transition curvature; \(r\) is the curvature radius of random point in the transition curve (m), \(l\) is the length from random point to the transition curve beginning point (m), \(Ls\) is the transition curve length (m), \(R\) is the circle curve radius of transition curve end (m). The transition curvature changes relatively slow when the parameter value \(C\) is large, this can make the drivers feel alignment is consistency and handle steering wheel easy. On the contrary, when the value \(C\) is small, the drivers handle steering wheel hard, this can cause accident easy. So it should adopt larger value of parameter \(C\) as possible [44]. Some studies have concluded that transition curves are dangerous because of driver underestimation of the severity of the horizontal curvature [58, 59]. Stewart [60] reports of a California Department of Transportation study involving a study of roads without transition curves which showed that roads with and without transition curves, which showed that roads with transition curves had, on average 73% more injury accidents (probability \(\neq 1\)) than the others. Also the Department Report "Accidents on Spiral Transition Curves in California" recommends against any
use of these curves. However, it is understood that recent studies in Germany and the UK have concluded that impact of transitions on safety in neutral [47].

4.2.5 Sight Distance

Sight distance is defined as the length of carriageway that driver can see in both the horizontal and vertical planes [61]. It is important for traffic accident. It will obviously bring high accident rate if the sight distance is not enough and this is visible on the places where have the bad visual distance of small horizontal curve radius, small crest vertical curve radius, intersection, and lack of overtaking sight distance on some road section. In order to ensure traffic safety, the traveling sight distance should be design enough when design horizontal or vertical alignment [44]. Sight distances include stop vehicle sight distance and passing vehicle sight distance. Stopping sight distance is the distance required by the driver in order to be able to stop the vehicle before it hits an object on the highway [61]. This is the minimum sight distance provided and is one of the major factors controlling the cost and the environmental impact of road design since it is provision affects the size of many other design elements. Although minimum stopping sight distances are specified on safety grounds, little information is available on the relationship between stopping sight distance and safety. However, it is generally accepted that short sight distances are dangerous [5]. So stopping sight distances for different design speeds are listed as follow Table (2). Passing sight distance is the minimum sight distance required for the driver of one vehicle to pass another vehicle safety and comfortably. Passing must be accomplished assuming on coming vehicle comes into view and maintains the design speed without reduction, after the overtaking maneuver is started [62]. Passing sight distance is of central importance to the efficient working of given section of highway. Passing sight distance only applies to single carriageways. Full passing sight distances are much larger in value than stopping sight distances. Therefore, economic realities dictate that they can only be complied with in relatively flat terrain where alignments, both vertical and horizontal, allow the design of a relatively straight and level highway [61]. Values for different design speeds are given in Table (3). However, no relationship between the length or proportion of passing sight distance and accidents could be located [5].

Table (2): Stopping Sight Distance for different design speeds [61]

<table>
<thead>
<tr>
<th>Design Speed (km/hr)</th>
<th>120</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>30</th>
<th>20</th>
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<tbody>
<tr>
<td>Stopping Sight Distance (m)</td>
<td>210</td>
<td>160</td>
<td>110</td>
<td>75</td>
<td>40</td>
<td>30</td>
<td>20</td>
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</table>

Table (3): Passing Sight Distance for Different Design Speeds [61]

<table>
<thead>
<tr>
<th>Design Speed (km/hr)</th>
<th>120</th>
<th>100</th>
<th>80</th>
<th>60</th>
<th>40</th>
<th>30</th>
<th>20</th>
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</thead>
<tbody>
<tr>
<td>Passing Sight Distance (m)</td>
<td>–</td>
<td>580</td>
<td>550</td>
<td>350</td>
<td>200</td>
<td>150</td>
<td>100</td>
</tr>
</tbody>
</table>

In general sight distance affects road safety since the sight distance is the result of the geometry overlapped with the existing terrain and the influence of geometric parameters is proved [4]. In some of studies various radii which correspond to different sight distance were investigated. The radii and sight distances were subdivided into groups. Especially in curves with small radii (R < 400 m) the accident rate is much higher than in other curves if the sight distance is shorter than 99 m. With increasing sight distance the difference between the curves getting smaller [4]. On sites with short sight distances due to vertical curves (e.g. crests) the accident frequency is 52% [18]. Hall and Turner [63] found that inadequate stopping sight distance does not guarantee that accidents will occur. Glennon [55] points out that improving sight distances in curves is associated with high cost effectiveness, especially when low cost measures such as clearing vegetation etc. are realized. He found that improving sight distances on crest is only effective if the road is characterized by a high
traffic volume. Hedman [64] found that accident rates decrease with increasing sight distance. But if the sight distances are above the stopping sight distance but below the overtaking sight distance drivers may start overtaking maneuvers even though the sight distance is too short for passing. In Lamm et al. [20] high accident rates were determined for sight distances short than 100 m. Above 150 m no further positive effect was determined. Elvik/Vaa [22] worked out that improving sight distance does not lead inevitable to a decline of accident risk. They figured out that improvements of short sight distances of 200 m to more than 200 m caused a significant worsening of accident risk. Several research works have shown the influence of sight distances on road safety. Especially short sight distances correspond with high accident frequency. Also was shown that an improvement is not only characterized by positive aspects. Larger sight distances which suggest the possibility of overtaking might cause accident even though the full overtaking sight distance does not exist [4].

4.2.6 Gradients
Steep gradients are generally associated with higher crash rates. Hedman [12] quoting Swedish research, stated that grades of 2.5% and 4% increase crashes by 10% and 20%, respectively, compared with near-horizontal roads. Glennon et al. [65] after examining the results of a number of studies in the United States, concluded that grade sections have higher accident rates than level sections, steep gradients have higher accident rates than mild gradients and down gradients have higher accident rates than up gradients. Department of Transportation [66] included a graph related to the base accident rate to that on gradients which concurs with Glennon [65] conclusions. Simpson and Kerman [47] noted that the overall accident implications of steep gradients are not serving as it would appear first, since steep gradients have shorter lengths. Transportation Research Board [16] concluded that the accident rate increases with gradients on curves.

4.2.7 Crest Curves
Minimum vertical crest curves are generally based on the provision of stopping sight distance at all points along the curve. TRB Special Report 214 [67] includes an equation from which the accident frequency on a segment of roadway containing a single crest vertical curve and its tangent approaches can be estimated; it concludes that the geometry of vertical curves is not known to have a significant effect on accident severity. However, Srinivasan [30] stated that "frequent changes in vertical alignment also result in a reduction in sight distance at the crest of vertical curves and these have been shown to be related to accidents, both in respect of frequency of occurrence and degree of sight obstructions"; the combination of gradient and superelevation on curves is important [5].

4.2.8 Sag Curves
The length of a sag curve is related to the stopping sight distance, the algebraic difference in gradients, the upward spread of the headlamps, etc. There is a lack of information on the safety impacts of sag curves. It has been stated that relaxations in stopping sight distance on sag curves in relatively flatter rain have no significant effect [5, 66].

4.2.9 Road surface Conditions
Traffic, weather conditions and ground conditions expose road surface to wear and tear. Ruts, cracks and unevenness in the road surface reduce driving comfort and can be a traffic hazard. They may make it more difficult to keep a motor vehicle on a steady course. Besides large holes in the road surface can damage vehicles and lead to the driver losing control of his vehicle. Evenness and friction are two important characteristics that influence road safety. Evenness is a measure of the regularity of a road surface. All types of road surfaces (rigid, flexible, gravel, etc.) deteriorate at a rate which varies according to the combined action of several factors: axial load of vehicles; traffic volumes; weather conditions; quality of materials; construction techniques. These deteriorations have
an impact on the road surface roughness by causing either cracking, deformation or disintegration. Various indicators can serve to estimate the quality of the longitudinal evenness of a road surface, but the international Roughness index (IRI), developed by the World Bank in the 1980’s, is the one most used today. The (IRI) measures the vertical motion of the suspension of the vehicle traveling on the road under standardized testing conditions ( meter of vertical displacement per kilometer driven). Skid resistance of pavement is the friction force developed at the tire-pavement contact area. In other words, skid resistance is the force that resists sliding on pavement surface. This force is an essential component of traffic safety because it provides the grip that a tire needs to maintain vehicle control and for stopping in emergency situations [4]. Skid resistance has two major components: adhesion and hysteresis. Adhesion results from the shearing of molecular bonds formed when the tire rubber is pressed into close contact with pavement surface particles. Hysteresis results from energy dissipation when the tire rubber is deformed when passing across the asperities of a rough surface pavement [68].

Difficult numerical values of skid friction are used around the world. In Sweden, road surface wet friction is measured with fixed slip devices (Skiddometer BV-11 or Saab Friction Tester, SFT). Friction values of 0.5 are desirable. Finland established the levels of acceptable friction as a function of speed as shown in Table (4)[69, 70].

In the U.K., a policy was developed to establish acceptable friction levels for different road and traffic situation. Friction levels are caked investigatory levels where an investigation or surface treatment needs to be made if friction is at or below this level. Table (5) summarizes the values taken with the SCRM device (Side force Coefficient Road Inventory Machine).

**Table (4): Typical Skid Resistance Value in Finland [69,70 ]**

<table>
<thead>
<tr>
<th>Speed (km/h)</th>
<th>Speed (mph)</th>
<th>Acceptable Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 80</td>
<td>≤ 50</td>
<td>0.4</td>
</tr>
<tr>
<td>≤ 100</td>
<td>≤ 60</td>
<td>0.5</td>
</tr>
<tr>
<td>≤ 120</td>
<td>≤ 75</td>
<td>≥ 0.6</td>
</tr>
</tbody>
</table>

**Table (5): U.K’s Investigative Skid Resistance Values [4 ]**

<table>
<thead>
<tr>
<th>Skid Resistance Measure</th>
<th>Site Category</th>
<th>Skid Resistance Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCRM at 50 km/h</td>
<td>A- Motorway (mainline)</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>B- All-Purpose dual carriageway-non-event sections</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>C- Single carriageway - non-event sections</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>D- All-Purpose dual carriageway – minor junctions</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>E- Single carriageway – minor junctions</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>F- Approaches to and across major junctions</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>G1- Grade 5 to 10% longer than 50 m</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>G2- Grade &gt; 10%, longer than 50 m</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>H1- curve with radius ≥ 250 m not subject to 65 km/h speed limit or lower</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>J- Approach to roundabout</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>K- Approach to traffic signals, pedestrians crossings railway level crossings or similar</td>
<td>0.55</td>
</tr>
<tr>
<td>SCRM at 20 km/h</td>
<td>H2- Curve with radius ≥ 100 m not subject to 65 km/h speed limit or lower</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>L- Roundabout</td>
<td>0.55</td>
</tr>
</tbody>
</table>
A study of the Finnish National Road Administration examined the extent to which drivers take pavement slipperiness into consideration [69, 71]. Drivers were asked to evaluate the roadway slipperiness on a scale measured and divided into four categories of friction coefficients (f):

- Good grip (f ≥ 0.45)
- Fairly good grip (0.35 ≤ f < 0.45)
- Fairly slippery (0.25 ≤ f < 0.35)
- Slippery (f < 0.25)

The results showed that drivers were poor at evaluating actual road conditions. Less than 30 percent of the evaluations coincided with the measured values, and more than 27 percent differed by 2 to 3 the categories listed above. According to the study, as friction values decreased, the relationship between driver's estimate of friction and actual conditions increased. Consequently, the skid resistance of the pavement did not have significant influence on driving speed. In 1984, the international Scientific Expert Group on Optimizing Road Surface Characteristics of the (OECD) Organization for Economic Co-operation and Development indicated that in the U.S. any reduction in friction was associated with a steady increase in accidents. Detailed analyses revealed a linear crash-skid resistance relationship as the proper function for interpreting the data. This behavioral function conflicts with other relationships obtained from Europe. A study of high-speed rural roads in Germany suggested a non-linear relation, with a higher slope for low friction values than for high friction values. Wallman and Astrom [69] also reported a similar regression analysis in Germany by Schulze [72]. Another study described by Wallman and Astrom with similar behavior is the Norwegian Veg-greosprosjektet. In this study, comprehensive friction measurements and roadway observations were completed resulting in the assessment of crash rates for different friction intervals as summarized in Tables (6) and (7).

**Table (6): Crash Rates for Different Friction Intervals [69]**

<table>
<thead>
<tr>
<th>Friction Interval</th>
<th>Accident Rate (personal injuries per million vehicle kilometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.15</td>
<td>0.80</td>
</tr>
<tr>
<td>0.15 – 0.24</td>
<td>0.55</td>
</tr>
<tr>
<td>0.25 – 0.34</td>
<td>0.25</td>
</tr>
<tr>
<td>0.35 – 0.44</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**Table (7): Crash Rates at Different Roadway Conditions [69]**

<table>
<thead>
<tr>
<th>Roadway Condition</th>
<th>Accident Rate (personal injuries per million vehicle kilometers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry are roadway, winter</td>
<td>0.12</td>
</tr>
<tr>
<td>Wet bare roadway, winter</td>
<td>0.16</td>
</tr>
<tr>
<td>Slush</td>
<td>0.18</td>
</tr>
<tr>
<td>Loose snow</td>
<td>0.30</td>
</tr>
<tr>
<td>Ice</td>
<td>0.53</td>
</tr>
<tr>
<td>Hoarfrost</td>
<td>0.53</td>
</tr>
<tr>
<td>Packed snow</td>
<td>0.31</td>
</tr>
<tr>
<td>Bare ruts</td>
<td>0.12</td>
</tr>
<tr>
<td>Black ice in ruts</td>
<td>0.30</td>
</tr>
<tr>
<td>Dry bare roadway, summer</td>
<td>0.14</td>
</tr>
<tr>
<td>Wet bare roadway, summer</td>
<td>0.18</td>
</tr>
</tbody>
</table>
5. CONCLUSION

After reviewing on the many studies which are related the safety of cross-section and alignment elements can be concluded the following:

- Lane and shoulder conditions directly affect run-off road (ROR) and opposite direction (OD) accidents. Other accident types, such as rear-end and angle accidents, are not directly affected by these conditions.
- The presence of a median has the effect of reducing specific types of accidents, such as head-on collisions. Medians, particularly with barriers, reduce the severity of accidents.
- Rates of ROR and OD accidents decrease with increasing lane and shoulder width. However, the marginal effect of lane and shoulder width increments is diminished as either the base lane width or shoulder width increases.
- On multilane roads, the more lanes that are provided in the traveled way, the lower the accident rates.
- Shoulder wider than 2.5m give little additional safety. As the median shoulder width increase, accidents increase.
- From the limited information available, it appears that climbing lanes can significantly reduce accident rates.
- Lane width has a greater effect on accident rates than shoulder width.
- Larger accident rates are exhibited on unstabilized shoulder, including loose gravel, crushed stone, raw earth or turf, than on stabilized (e.g. tar plus gravel) or paved (e.g. bituminous or concrete) shoulders.
- The probability of an accident two-lane rural roads is highest at intersections, horizontal curves and bridges. The average accident rate for highway curves is about three times the average accident rate for highway tangents.
- Horizontal curves are more dangerous when combined with gradients and surfaces with low coefficients of friction. Horizontal curves have higher crash rates than straight sections of similar length and traffic composition; this difference becomes apparent at radii less than 1000 m. the increase in crash rates becomes particularly significant at radii below 200 m. Small radius curves result in much shorter curve lengths and overall implications for crashes may not be as severe as would first appear.
- There is only a minor decrease in the speed adopted by drivers approaching curves of radii which are significantly less than the minimum radii specified for the design speed. However, curve radii below 200 m have been found to limit the mean speed to 90 km/hr.
- The average single vehicle accident rate for highway curves is about four times the average single vehicle accident rate for highway tangents. Regarding general terrain descriptions it was found that accident rates in mountainous terrain can be 30 percent higher than in flat terrain.
- Crashes increase with gradient and down-gradients have considerably higher crash rates than up-gradients. However, the overall crash implications a steep gradients may not be severe since steeper gradients are shorter. The geometry of vertical curves is not known to have a significant effect on crashes severity.
- There appears to be little erosion of safety resulting from the use of sight distances below the minimum values specified in geometric design standards, although there is a significant increase in the accident rate for sight distances below 100 m.
REFERENCES


[63] Hall J.W., Turner D.S., "Stopping Sight Distance: Can We See Where We Now Stand", Transportation Research Record 1208, 1989.


