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The Comparison between IHSDM and NSM to Assess the Safety Performance of Two-Lane Rural Roads

Dissertation
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By

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To

My father in heaven

who always lives in my mind,

My mother

who always encourages me,

and my lovely husband and my son,

who are all my life.

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Abstract

The objectives of this research were to explore ways to assess the safety performance of two-lane rural roads in NRW (North Rein Westphalia, Germany), and in particular to identify road factors affecting accidents on rural roads. Following a wide-ranging literature review, the Interactive Highway Safety Design Model (IHSDM) was identified as worthy of further investigation for its adaptation to use. Initial investigations showed that IHSDM is a promising tool for safety and operational assessment of two-lane rural roads in Germany. Incorporating crash history data generally improves IHSDM's accuracy in crash numbers, and appears to provide a better level of "local calibration". A number of tasks were identified and undertaken to adapt IHSDM for general use here, including calibrating the Crash Prediction Module (CPM), developing a Design Policy file based on local agency standards for use within the program, and developing an importing routine for the highway geometry and accident data.

This research aims to present and illustrate a comprehensive road safety method: Network Safety Management (NSM). NSM, based on the German Guidelines for Safety Analysis of Road Networks ESN, describes a methodology for analyzing road networks from the traffic safety point of view. It also helps the road administrations in detecting those sections within the network with the highest safety potential, i.e. where an improvement of the infrastructure is expected to be highly cost efficient. Suitable measures can then be derived from a comprehensive analysis of the accidents. The safety potential and the calculated cost of the measure together form the basis for an economic assessment, which is usually conducted as a cost–benefit analysis.

A systematic algorithm to assess traffic accident risk in the study area was developed in this study. The algorithm helps to identify factors that have significant influence on accidents, and to identify the road sections that have high risk of accidents. This algorithm provides both geographical and statistical analysis on accident events, i.e. mapping "Safety Analysis of Road Networks ESN" and statistical techniques "cluster analysis".

Zusammenfassung

Diese Forschungsarbeit hat als Ziel, die Sicherheitseffizienz zweispuriger Landstraßen in Deutschland (NRW) zu berechnen und insbesondere die Unfallfaktoren auf diesen Straßen zu ermitteln. Nach intensiver Literaturrecherche wurde festgestellt, dass das in den USA entwickelte Interactive Highway Safety Design Model (IHSDM) für weitere Untersuchungen genutzt werden kann. Die anfänglichen Untersuchungen haben ergeben, dass IHSDM ein vielversprechendes Sicherheits- und Bewertungsinstrument für zweispurige Landstraßen in Deutschland ist. Unfalldaten aus den Jahren zuvor zeigen, dass das IHSDM Informationen bereitstellt, die es erlauben, Maßnahmen zu benennen, um die Unfallzahlen zu verringern. Zudem bietet es vom Ansatz her eine gute Basis für die „Kalibrierung vor Ort“.

Die Untersuchungen haben ergeben, dass das IHSDM für den allgemeinen Gebrauch in Deutschland angepasst werden muss. Vor allem müssen das Crash Prediction Module (CPM) kalibriert werden, eine Design-Policy-Datei basierend auf den lokalen Richtlinien entwickelt werden und eine Import-Routine für die Straßengeometrie und die Unfalldaten entwickelt werden. Das Ziel dieser Forschungsarbeit ist, einen Vergleich der IHSDM -Methode mit der Methode„Network Safety Management NSM“herzustellen. NSM ist eine Methode, die auf den deutschen Richtlinien für Sicherheitsanalysen von Straßennetzen ESN basiert. Sie analysiert Straßennetze, wobei die Verkehrssicherheit im Blickpunkt steht, und hilft dem Straßenverkehrsamt die Abschnitte mit dem höchsten Sicherheitspotenzial innerhalb des Netzes zu erfassen, beispielsweise wenn zu erwarten ist, dass eine Verbesserung der Infrastruktur in hohem Maße kosteneffizient ist. Allerdings liefert NSM nur indirekt Ansatzpunkte für eignete Maßnahmen, die aus den umfassenden Analysen der Unfälle abgeleitet werden müssen. Somit bietet es sich an, ein an deutsche Verhältnisse angepasstes IHSDM für die Untersuchung von Unfällen und die Entwicklung von Reduktionsstrategien einzusetzen.

In der vorliegenden Studie wurden beide Methoden ein systematischer Algorithmus zur Feststellung des Unfallrisikos im Untersuchungsgebiet entwickelt. Der Algorithmus hilft, ausschlaggebende Unfallfaktoren und Streckenabschnitte, die eine hohe Unfallgefahr besitzen, zu identifizieren. Er bietet sowohl geographische als auch statistische Analysen zu Unfallereignissen, wie zum Beispiel einer Kartierung der "Sicherheitsanalyse von Straßennetzen ESN" sowie statistischer Methoden wie der "Clusteranalyse".

Contents

Abbreviations

A	number of accidents
AADT	annual average traffic volume
AASHTO	american association of state highway and transportation officials
AC	accident costs
AC_a	annual average accident cost
ACD	accident cost density
ACR	accident cost rate
AD	accident density
ADT	average daily traffic
AMFs	accident modification factors
ANOVA	analyses of variance
AR	accident rate
ATS	average travel speed
B	bundesstrasse
bACD	basic accident cost density
BASt	federal highway research institute
BMVBS	bundesministerium für verkehr, bau und stadtentwicklung
CCRs	curvature change rate
CPM	crash prediction module
C_r	calibration factor for highway segments
CSV	comma separated values
DCM	design consistency module
DPM	driver performance model
DVM	driver/vehicle module
EB	empirical bayes
E_p	expected crash frequency
ESN	german guidelines for road safety analysis of road networks
EuroRAP	european road assessment programme
F	fatal crash
FHWA	federal highway administration
FinnRA	finnish national road administration
HCM	highway capacity manual
IHSDM	interactive highway safety design model
IRM	intersection diagnostic review module
L	length of road section
L	landesstrassen
LI	light injury crash
MCA	mean cost per accident
N_{br}	predicted number of total highway segment crashes
N_{rs}	predicted number of total highway segment crashes per year,

NRW	north rhine westphalia
NSM	network safety management
NWSIB	strasseninformationsbank nordrhein-westfalen
OD	opposite direction accidents
OECD	organization for economic co-operation and development
PDO	property damage only crash
PRM	policy review module
PSD	passing sight distance
PTSF	percent time-spent-following
R	radius of circular curve
RAS-Q 96	richtlinien für die anlage von straßen, teil: querschnitte
RHR	roadside hazard rating
ROR	run-off-road accidents
SAFESTAR	safety standards for road design and redesign
SAPO	safety potential
SAT	system administration tool
SI	serious injury crash
SSD	stopping sight distance
t	period of time under review
TAM	traffic analysis module
TERN	trans-european roadway network
TWLTL	two-way left-turn lane
TWOPAS	two-lane passing
V_{85i}	expected 85th percentile speed of design element “i”
V_{85i+1}	expected 85th percentile speed of design element “i+1”
V_d	design speed, km/h.
VDM	vehicle dynamics model
VPI	vertical point of intersection

1 Introduction

1.1 General

Unfortunately, most people are unaware of how large a problem unsafe traffic operation is on a worldwide basis. The tragic consequence of traffic accidents puts unsafe traffic operations on a par with war or drug use [1]. Whereas most traffic crashes occur in urban areas, the rates of fatal crashes and traffic fatalities are higher in rural areas. In Germany, nearly 60 % of all fatal accidents in 2005 occurred on rural roads (based on data of the Federal Highway Research Institute BASt) [2].

A major distinction between the assessment of urban and rural road safety is the importance of road features in determining the likely crash rates in rural areas. The distinction makes itself apparent in the greater number of single-vehicle crashes on rural roads, and in the influence that road features have on both the likelihood and severity of these crashes. In an urban environment, drivers are usually more constrained by speed limits and other road users. At the higher speeds found on rural roads, sight distances also become more important when considering crashes involving multiple vehicles or unexpected obstructions [3,4]. Table 1-1 shows a comparison of some of the key accident statistics between urban and rural roads in Germany for one calendar year (2002) [5].

Moreover, the low population density and geographic isolation of rural communities can increase detection, response, and travel time for emergency medical services, thereby reducing crash survivability. In addition, the human factors associated with common impairment states and driving behaviors amongst rural drivers are significant contributors to rural fatal crashes [3].

Table 1-1: Comparison of accident statistics, reported Traffic in Numbers 2002 [5].

Variable	Urban roads	Rural roads
Proportion of fatal accidents (6,842 in total)	24.6 %	75.4 %
Proportion of injury accidents (476,400 in total)	60.5 %	39.5 %
Proportion of serious accidents(88,400 in total)	47.6 %	52.4 %
Proportion of light injury accidents (388,000 in total)	63.4 %	36.6 %
Proportion of fatal+injury accidents (483,242 in total)	60.0 %	40.0 %

1.2 Problem statement

Rural road safety accounts for a considerable share of the total road safety problem. In order to improve road safety, the actual dangers and problems need to be identified, and measures should be targeted to tackle road safety problems.

The purpose of the research outlined in this thesis is to identify road characteristics that can be used to predict roadway risk and safety potential, including cross-section, horizontal alignment, vertical alignment, driveway density, roadside hazard rating and sight distance. The safety repercussions of geometric design decisions can then be assessed.

This was accomplished by collecting existing characteristics and accident histories (in Landkreis Mettmann and Wuppertal, Solingen and Remscheid Kreisfreie Städte) to determine the impact of roads' geometric characteristics on the safety of rural roads.

1.3 Research objectives & scope

The research study has been undertaken to investigate and evaluate the safety performance of geometric design for two-lane rural roads in Landkreis Mettmann and Wuppertal, Solingen and Remscheid Kreisfreie Städte. The main objectives of this research are:

- to identify road factors affecting accidents on rural roads;
- to analyze the rural roads based on Network Safety Management (NSM) to find measures that have the highest accident reduction potential, i.e. considering the parts of the network where the most can be gained in relation to the cost;

- to assess the accident risk by using algorithms (mapping “NSM” and statistical techniques “cluster analysis”);
- to identify the tasks required to adapt Interactive Highway Safety Design Model (IHSDM) for use in Germany and then to undertake these adaptations;
- to assess the effectiveness of IHSDM in Germany for predicting the relative safety of a rural road;
- and to compare among the three methods, Preliminary & Regression Analyses, NSM and IHSDM.

This research was achieved by a combination of literature review, and analysis of highway and accident data.

1.4 Road safety assessment processes

Figure 1.1 summarizes and describes the methods that were undertaken in the dissertation to assess the road safety performance.

1.5 Dissertation structure

The remaining parts of this thesis are organized as follows.***Chapter 2*** is the literature review that traces a number of important studies that have contributed to knowledge of the effect of road geometry on road safety. This chapter also reviews the rural road safety model IHSDM. ***Chapter 3*** outlines the methodology of study segments and data collection used in this work. ***Chapter 4*** consists of data analysis and evaluation. The evaluation and adaptation of the model (IHSDM) is then discussed in ***Chapter 5***. Finally, ***Chapter 6*** assesses the important conclusions from this study and suggests future areas of research.

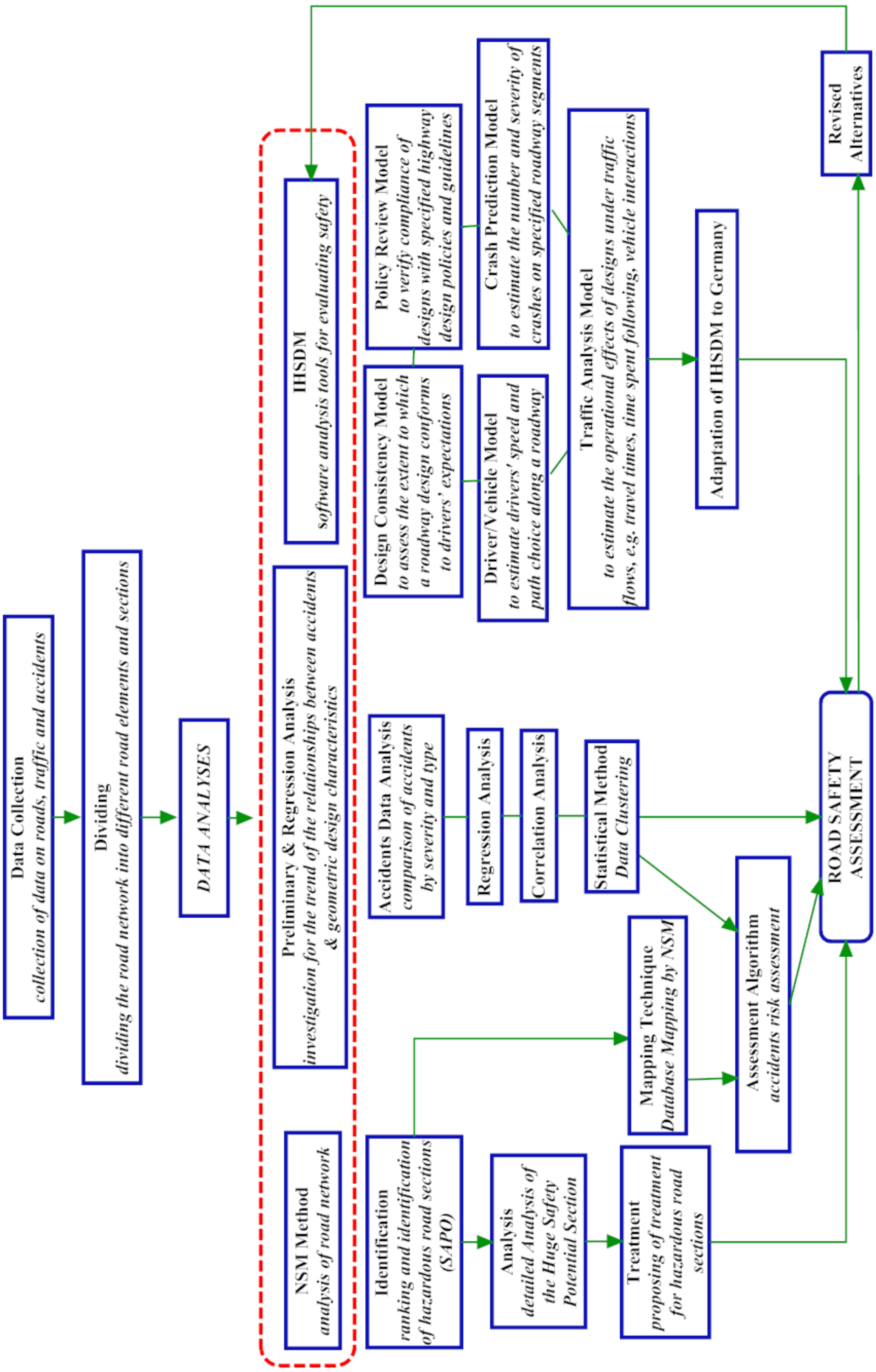


Figure 1.1: Flowchart of the road safety assessment processes.

2 Literature Review

2.1 Introduction

A large number of studies have been conducted to characterize and quantify the relationships between traffic safety and highway characteristics. It would be impossible to mention all of them in the space available. However, a summary of the major conclusions regarding the effect of driver, vehicle and road environment factors on safety will be given.

2.2 Characteristics of rural crashes

Rural road trauma has been a major concern worldwide for many decades. For example, in OECD countries, traffic crashes in rural areas account for some 60% of all road deaths [6].

Both crash and injury risk on rural roads differ from those on urban roads. While crash rates are generally higher in urban areas (because of the greater number of intersections and higher traffic volumes), crashes on rural roads tend to be more severe (because of the greater speeds and diversity of road conditions). The key contributing elements to the increased severity of rural crashes compared to urban crashes include higher operating speeds, hazardous roadsides, and generally poorer road geometry, multi-functionality and lower enforcement levels [4].

European countries, the United States and Australia all report high rates of death and injury on rural roads. Many road related deaths in Europe (40%) occur on major roads outside built-up areas, most being on single-carriageway roads with speed limits of more than 80 km/h [7].

In England, for example, nine percent of deaths on major roads outside built-up areas are on the motorways, 19% on dual carriageways, 38% on single carriageways of national and regional importance, and 34% on other single carriageways [7]. In Denmark, approximately 30% of all traffic crashes occur in rural areas. More importantly, rural crashes comprise 44% of all casualties and 64% of all fatalities [8]. The Danish road network consists predominantly of two-lane roads with a speed limit of 80 km/h and it is here that the largest proportion of crashes in rural areas occurs. Swiss data, similarly, indicate high crash and injury risk on rural roads. The death rate is estimated to be five times higher on rural roads than on motorways and about 4% higher than in built-up areas [9]. Based on data of the Federal Highway Research Institute (BASt), nearly 60% of all fatal accidents in Germany occur on rural roads [2].

In his overview of the rural road safety problem in Australia, Henderson [10] noted that nearly half of all fatal crashes occurred on rural roads and another 14% in regional towns. Lydon [11], similarly, reported that approximately 48% of all fatal, and 40% of casualty crashes occur in rural areas. In the State of Victoria alone, Ogden [12] reported that about one-third of fatal crashes and one-fifth of casualty crashes take place on open roads in rural areas.

In the USA, crash and fatality rates on low-volume rural roads are higher than other highways [13]. Tessmer [14] undertook a comparative analysis of rural and urban crashes in the USA and noted the following:

- There are approximately 40% more crashes, vehicles involved, individuals involved and deaths in rural areas than in urban areas, even though there are fewer vehicle kilometers traveled in rural areas compared to urban areas;
- While fatal crashes occur mostly on roads with 55 mph (89 km/h) speed limits in both rural and urban areas, rural roads with this speed limit account for almost 70% of rural fatal crashes, whereas urban roads with this speed limit account for 22% of urban fatal crashes;
- Rural fatal crashes result in multiple deaths 21% of the time, whereas urban fatal crashes result in multiple deaths seven percent of the time;
- A larger proportion of rural fatal crashes involve trucks compared to urban fatal crashes (22% and 10% respectively);

- The proportion of fatal rural crashes that involve head-on collisions (25%) is higher than the proportion of fatal urban crashes that involve head-on collisions (15%);
- A larger proportion of individuals in fatal rural crashes are passengers (40%) than in urban crashes (32%), but fewer pedestrian fatalities occur in rural areas compared to urban areas (4% compared to 11%);
- Crashes involving a single vehicle striking a fixed object or a vehicle rollover are more prevalent in rural areas than urban areas, while a vehicle striking another vehicle occurs with greater frequency in urban crashes than in rural crashes;
- The proportion of males involved in rural crashes is higher than the corresponding proportion of males involved in urban crashes;
- And rural crashes result in a more severe injury outcome than urban crashes; an individual involved in a crash is up to three times more likely to die as a result of rural crashes than from an urban crash.

Travel on rural roads usually occurs at high speeds. Single-vehicle crashes typically account for 30-40% of injury-producing crashes. Single-vehicle crashes mostly involve vehicles leaving the roadway and colliding with rigid objects or overturning. It is common for errant vehicles to strike roadside trees, poles, embankments or a variety of man-made structures. Vehicles overturn when roadsides are uneven, too steep, or both. Crashes in which vehicles overturn or strike roadside hazards tend to result in severe injuries because of the rigid nature and often narrow dimensions of the objects struck, as well as the high impact speeds [4].

Wegman [15] reported that 32% of rural crashes in the Netherlands involved a single vehicle hitting a fixed object. Likewise, Toivonen and Niskanen [16] showed that, on semi-motorways in Finland (particularly lower volume roads), single-vehicle crashes accounted for a little over one-third of all crashes resulting in injury or death. Haworth et al. [17] estimated that single-vehicle crashes comprise approximately 30% of road trauma in Victoria, Australia. Similarly, Gelston [18] reported that a high proportion of rural fatal crashes (60-65%) and rural casualty crashes (60%) in South

Australia involved a single vehicle running off the road (compared with only 25% and 15-20% for metropolitan areas respectively).

A number of 'causes' for these types of crashes have been identified, including: excessive speed, wheels on the verge or soft shoulder, fatigue and alcohol [8]. Single-vehicle run-off-road crashes generally occur following loss of control (often on sealed roads with unsealed shoulders).

Multi-vehicle collisions are also an important source of road trauma in rural areas. Collisions at intersections, head-on impacts and rear-end collisions (or similar) are the main multi-vehicle crash categories in rural areas. Again, injuries tend to be severe because of the high impact speeds and the inability of vehicles adequately to protect their occupants in many of the common crash types at these speeds. Head-on impacts and intersection crashes involving side-impacts occur frequently and with high severity [4].

McLean et al. [19] reported that, of those crashes in which more than one vehicle was involved, the most common crash type was a mid-block collision. Head-on collisions comprised half of the sample and were generally severe. A majority of the head-on collision cases resulted from one vehicle running onto the unsealed shoulder on the left, and then overcorrecting and veering back across the road out of control. Again, crashes were caused by unsealed shoulders, particularly on curved sections of road and where there were problems with the road surface.

The US Department of Transportation's (DOT) Rural Safety Initiative highlighted the key characteristics of rural crashes as the following: [20]

- *A disproportionate number of fatalities*: Although 23% of the US population lived in rural areas in 2006, rural fatal crashes accounted for 55% of all traffic fatalities.
- *Less exposure, yet more fatalities*: While the majority of deaths occur on rural roads, fewer miles are driven there. In 2006, just over 1 trillion miles were driven on rural roads verses approximately 2 trillion miles on urban roads.
- *A higher fatality rate*: The fatality rate per 100 million vehicle miles traveled was more than double in rural areas than it was in urban areas (2.25 and 0.93 respectively).

- *Less seat-belt usage in rural areas*: 57% of all the people who died on rural roads were not restrained, compared to 52% in urban areas. Last year, the seat-belt use rate among occupants of vehicles in urban areas was 84% compared to 78% in rural areas. In 2006, 68% of fatally injured pickup truck drivers were unrestrained; the restraint use rate among these drivers is the lowest of any vehicle type.
- *More speeding fatalities*: In 2006, 12,190 drivers involved in fatal crashes were speeding; 57% were drivers in rural areas.
- *More impaired driving fatalities*: Of the passenger vehicle occupant fatalities involving impaired driving crashes (BAC .08+) in 2006, 58% were in rural areas. At most blood alcohol concentration (BAC) levels, the percentage of rural drivers involved in fatal crashes exceeds the percent of urban drivers involved at the same BAC.
- *A lethal combination*: In 2006, rural drivers made up 62% of the total number of drivers found to have been drinking, speeding and unrestrained.
- *Post-crash*: In 2006, 66% of rural drivers killed in crashes died at the scene, compared to 51% of urban drivers. 72% of drivers who died en route to a hospital were in rural areas.
- *Most fatalities occur on two-lane rural roads*: Nearly 50% of total highway fatalities occur on two-lane rural roads. The fatality rate overall on local roads is more than twice that of interstates.

2.3 Traffic safety and crash causation

Even though the human factor may be identified as a major cause of accident, it is virtually impossible to control and difficult to design for the driver’s frame of mind and physical condition. The highway engineer cannot influence alcohol abuse or seat-belt usage and has little capability to improve driver judgment at intersections. However, good geometric design should help to control traffic operating speeds and to reduce accidents brought about by excessive speeds that are inconsistent with conditions or geometry

Crashes are complex in nature, often involving several contributing factors. Nevertheless, a number of factors have been identified that influence crash and injury risk, including driver factors, vehicle factors, and road factors [21].

2.3.1 Driver characteristics

The driver's behavioral characteristics, such as inattention, fatigue, inexperience, and risk-taking behavior (speeding, drunk-driving, and failure to wear a seat-belt), have all been identified as factors that significantly contribute to increased crash and injury risk on rural roads.

Driver fatigue is a significant contributory factor to road crashes, particularly those on rural roads in most developed countries. Estimates of the contribution of driver fatigue vary from 4% to 25% [22]. An Australian study [23] estimated that 27% of single-vehicle crashes in rural areas were fatigue related.

The key component involved in run-off crashes is the driver's ability to control both speed and direction. Run-off occurs when a driver is faced with a piece of unexpected or unusual information, which leads him or her to over-correct at a large steering angle. Causes of this include: the driver's behavior; distractions (such as talking, eating, etc.); influence of alcohol, drugs or medication; drowsiness, fatigued, illness, or blackout; speeding; and failure to obey signs, signals or traffic officers, which could be due to confusion or unfamiliarity with the roadway [24].

The driver's age also plays an important role in crash causation: a younger driver could be inexperienced at driving, while an older driver has longer perception–reaction times for any type of safe vehicle maneuvers. From an older traveler's perspective, decrements in cognitive and psychomotor functions associated with the aging process increase their vulnerability to running off the road [25-27].

2.3.2 Vehicle characteristics

The crash protection capabilities of vehicles greatly affect the outcome of injuries. It seems that in real-world crashes, particularly on high-speed rural roads, even the best vehicles cannot protect their occupants or other road users in many common crash types.

Mechanical problems in vehicles are another important factor that contributes to traffic crashes [24]. Faulty brakes, worn tires and other vehicle defects affect the controlling of a vehicle, especially at high speeds. It has been observed that at high speeds the tires may blow out leading to loss of control. Tire tread separation is another factor that leads to loss of control. Vehicle and roadway interactions, such as skid resistance, play a major role in stopping the vehicle from encroaching the off-road features, like the shoulder, median and other traffic signage [28].

There are problems associated with heavy vehicles on rural roads. First, there is the problem of the mix of vehicles on rural roads, and the risk of injury to vehicle occupants involved in a crash with a heavy vehicle. Secondly, there is the problem of single-vehicle crashes involving heavy vehicles, and the contribution of road features to these crashes. Although crashes involving trucks are less common than those involving smaller vehicles, they tend to be more severe than those involving smaller vehicles. Haworth and Vulcan [29] noted that about 75% of fatal crashes involving articulated trucks occurred outside of capital cities, with 23% of these being single-vehicle crashes.

Heavy goods vehicles and buses have characteristics that are quite different from those of passenger cars. Essentially, the problems relating to heavy vehicles on rural roads result from three characteristics: *i)* heavy vehicles are much heavier and larger in dimension compared with passenger cars, and therefore experience instability and maneuverability problems; *ii)* heavy vehicles have less effective acceleration capabilities than passenger cars and have greater difficulty maintaining speeds on upgrades, and this speed variation generates more instances of overtaking and the potential for head-on collisions with oncoming vehicles; and *iii)* heavy vehicles have a lower deceleration in response to braking than passenger cars, which increases the potential for severe rear-end crashes [4].

2.3.3 Road characteristics

2.3.3.1 Speed

One of the key problems on rural roads (particularly single-carriageway roads) is that they often do not have consistent design characteristics over their total length. This means that drivers cannot drive safely at high speeds all the time and everywhere, since changes in the road environment require constant adaptions in speed. The requirement of adapting speed to suit the environment can increase the opportunity for human error and lead to higher risk of crash and injury. Driving too fast for the conditions is a major factor in crash causation and injury severity. The conjunction of high speeds and the varying geometric conditions common on rural single-carriageway roads results in a fatal crash rate that is higher than that for any other type of road [30].

A common thread across many safety issues is the relative speeds of the vehicles involved in crashes. This has implications for both the likelihood and severity of crashes on rural roads. For example, a large variance in vehicle speeds within a traffic stream appears to increase the likelihood of vehicle interaction and associated rear-end or overtaking crashes, while a greater traveling speed at the time of collision increases the expected severity of a crash [31].

Higher speeds increase both the probability of crash involvement and the seriousness of the consequences. Higher driving speed reduces the predictability for other road users and also reduces a driver’s ability to control the vehicle, negotiate curves or maneuver around obstacles on the roadway. This therefore increases the chance of running off the road or into an oncoming vehicle. Higher speed also increases the distance a vehicle travels while the driver reacts to a hazard, thereby reducing the time available to avoid a collision [4].

More importantly, a higher speed increases the severity of the impact in a collision. Even small increases in speed can result in a dramatic increase in the forces experienced by crash victims, and it is argued that the probability of sustaining an injury in a crash increases exponentially rather than linearly with vehicle speed [32-34].

As indicated previously, high speed on rural roads is a major issue, as maximum legal speeds tend to be relatively high in these environments (usually between 80 km/h and 120 km/h). Rural road speed-related crashes are some four times more severe than those in the urban area based on the relative difference in serious crash proportions [35]. In other words, although the risk of being involved in a speed-related crash relative to a non-speed-related crash is about the same in both types of road environments, once involved in such a crash the consequences are more severe on rural roads due to the higher speeds.

As noted by Lamm et al [1], speed has the greatest effect on traffic safety. He studied the effect of design speed on accident rates and accident cost rates, and concluded that the accident rate decreases as design speed increases from 60 to 80 km/h. However, for design speeds greater than 80 km/h, the accident rate did not decrease. On the other hand, the accident cost rate increased as the design speed increased throughout the range. This is understandable, assuming that for higher design speeds a more generous road design capable of supporting operating speeds was in place. These higher operating speeds led to more severe accidents.

Several studies have shown that there is a clear relationship between the speed level and the number of accidents; even small changes in the speed level result in significant changes in the number of accidents [32-34]. Finch's summary [33] of the US and German interstate/autobahn evidence is that a 1 mph decrease in mean traffic speed leads to a reduction in fatalities in the order of 8-10%. He also cites a number of statistical models, which suggest: *i)* a 5% rise in accidents for every 1 mph increase in mean traffic speed; *ii)* that the change in the accident rate is a power function of the change in the median traffic speed; and *iii)* that assuming there are asymptotic limits to the relationship, the maximum expected percentage change in accidents associated with a large increase in speeds would be 28%, while for a large decrease this figure would be 25%.

Many studies have examined the effect of raising or lowering speed limits in both rural and urban environments. Studies consistently show that crash incidence or crash severity decline whenever speed limits have been reduced [36]. A number of studies examined the effect of raising speed limits on rural highways from 55 mph (89 km/h) to 65 mph (105 km/h) on crash risk in the USA [37].

While the size of the effects differed across the States, there was a general increase in fatalities with the increase in speed limit, with increases in the number of fatalities in the order of 15–29%. Godwin [38] added that there was evidence that motorists had responded to this change by not only driving faster on the highways that had an increased speed limit, but also on highways without the change in speed limit.

One of the major issues in setting rural speed limits is the transition from the rural road network to the urban road network, i.e. the approach to and speed zones through rural townships. Indeed, some studies have shown that the crash and injury rate on major roads into and through country towns is substantially higher than on the open road [39]. One study investigated the casualty crashes on the approach to, or on the immediate outskirts of major provincial cities and towns in the State of Victoria, Australia. For roads extending from urban areas (60 km/h), through a speed transition zone or a partially developed area (75 km/h), to exclusively rural areas (100 km/h), Tziotis [40] reported a greater incidence of casualty crashes in partially developed speed transition zones (75 km/h) compared to rural zones (100 km/h). Specifically, in the first instance, Tziotis reported 45 casualties per 100 million km per year compared to 27 casualties per 100 million km per year, and in the second instance, 1.3 casualties/km/year compared to 0.4 casualties/km/year. Furthermore, the number of rear-end casualty crashes and casualty crashes involving either rigid trucks or motorcycles peaked within the transitional, partially developed zone, as did the proportion of casualty crashes occurring during the dusk or dawn period. Tziotis also noted that the changes in the nature of crashes that prevailed along these feeder roads had occurred within a relatively short length of the transition zone.

2.3.3.2 Road lengths

The overtaking maneuver on two-lane rural roads without the assistance of additional passing lanes is a complex driving task. It requires critical information-processing and decision-making skills, and a lengthy section of road to complete the maneuver (enough distance to allow a sufficiently large gap in the oncoming traffic, plus the distance traveled by that vehicle, plus a safety margin).

It appears that the rate of overtaking crashes is related to the provision and geometric design of passing lanes. When passing lanes are not provided on long sections of rural road lengths, there is increased potential for risky or misjudged overtaking maneuvers, particularly when sight distance is short. Further, it seems that design practices for passing lanes (in terms of passing zone lengths and number of passing zones) may not be appropriate for many drivers to pass slow traffic or multiple vehicles in a safe manner [4].

Research on overtaking crashes is comparatively rare, despite the frequency and severity of these types of crashes on rural roads. Crashes resulting from risky or misjudged overtaking maneuvers are typically fairly serious. They generally result in head-on, sideswipe or rear-end collisions and occur mainly on two-lane rural roads. Clarke, Ward and Jones [41] reported that overtaking crashes account for 8% of fatal crashes in Nottinghamshire, England, and that their crash severity index (the proportion of cases resulting in death or serious injury) is over 20%. In Australia, Armour [42] found that overtaking is involved in about 10% of rural casualty crashes. These rates are much higher than the reported 3-4% of such crashes in the USA [43] , which probably reflects the much greater length and usage of multilane, divided roads in that country.

Moreover, questions which have been raised about current design practices of passing lanes suggest that the geometric features of passing lanes affect crash risk. Hughes, Joshua and McGee [44] questioned the minimum length of 122 m for a passing zone in the USA, stating that, for design speeds above 48 km/h, the distance required for one vehicle to pass another is much longer than 122 m. Weaver and Glennon [45] reported that most drivers cannot pass even within a 244 m section, and that use of passing zones remains very low when their length is shorter than 274 m. Further, Polus, Livneh and Frischer [46] argued that in today's traffic, where 25% or more of passing maneuvers are multiple passings (i.e. where more than one vehicle is overtaken in one maneuver), longer distances are required and therefore longer sight distances than are specified in current guidelines. Hughes et al. [44] also noted that current minimum passing distances are inadequate for the abortive maneuver, and that they do not consider the length of the vehicle being overtaken.

2.3.3.3 Roadside characteristics

Single-vehicle crashes are common on the rural road network and they typically involve vehicles leaving the roadway and colliding with fixed objects on the roadside or overturning. These crashes generally result in serious injuries.

In combination with high speeds, an unforgiving roadside plays a major role in the frequency and severity of run-off-road crashes. This is largely because of the positioning and rigid nature of fixed objects, and because shoulders are unsealed, uneven or too steep [4].

The roadside environment has a significant influence on crash and injury risk. Sideslope and roadside ditch geometry both influence a driver's ability to recover from an unanticipated excursion off the paved surface. More importantly, roadside objects are the most notorious cause of serious injury in crashes on rural roads, and moreover single vehicles leaving the roadway and striking a fixed object have been identified as the most common crash type in rural areas in most countries [12,47]. Utility poles, trees, and non-yielding signs are some of the objects that cause serious problems on rural roads. Such objects have been and continue to be inconsistent with the notion of a forgiving roadside and create substantial trauma and costs for individuals and society [48]. In the USA, Wright and Zador [49] reported that run-off-road crashes account for between 15 and 53% of all road crashes, depending on the area studied, the type of road, and the time of day. In Canada, Cooper reported that at least one third of all fatal and other casualty crashes in rural areas involved single vehicles running off the road. In New Mexico, 45% of fatal crashes were single-vehicle crashes, with a high proportion of these being run-off-road crashes in sections of rural highways.

Sanderson and Fildes [47] analyzed run-off-road crashes in Victoria, Australia. They reported that 62% of vehicles struck a fixed object, and that these are commonly severe crashes, with 9% resulting in a fatality, 58% requiring hospitalization of at least one occupant, and 33% requiring medical attention. Interestingly, the severity outcomes were similar for the 38% of crashes where vehicles ran off the road but did not strike an object. Crashes of this type may cause serious injury as the vehicle encounters steep or uneven terrain and rolls over, or when the occupants are ‘flung around’ and strike other occupants or elements of the vehicle’s interior. Of those crashes in which a vehicle struck a fixed object, 47% involved striking trees or shrubs, 27% involved striking ‘essential’ features (e.g. bridges, fences, embankments or walls), and 20% involved hitting ‘introduced’ features (e.g. poles, guideposts or safety rails).

Another study in the same state found a similar proportion of single-vehicle run-off-road crashes [48]. Of the 5,184 serious casualty crashes in Victoria during 1994, 1,175 involved a single vehicle striking a fixed roadside object. These crashes were found to be severe in nature, accounting for 23% of all serious casualties on Victoria’s roads, with 1,454 people either seriously injured or killed in 1994 alone. The most common objects struck were trees, poles and embankments.

2.3.3.4 Cross-section elements

Most studies were limited to two-lane roads and showed that accident rates decreased with increasing width. However, Heame’s [50] results suggested that there was a marginal increase in accident occurrence with an increase in carriageway width. Hedman [51] noted that some results indicated a rather steep decrease in accidents with increased width of carriageway from 4 m to 7 m, but that little additional benefit is gained by widening the carriageway beyond 7 m. This is supported by the NCHRP Report 197 [52] conclusion that there is little difference between the accident rate for a 3.35 m and a 3.65 m lane width. However, studies on low-volume rural roads indicate that accidents continue to reduce for widths greater than 3.65 m, although at a lower rate [53].

Yagar and Van Aerde [54] 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 3.3 m to 3.8 m, they reported that the operating speed is decreased by approximately 5.7 km/h for each 1 m reduction in the width of the road.

In Denmark [55] it was found that as the lane width increases the relative accident frequency decreases; for road widths of under 6 m, there was an increase in the risk of both injury accidents and severe injury accidents. This is supported by Srinivasan [56], who reported that "the accident rate of a 5 m road was about 1.7 times that of a 7.5 m road". A comprehensive Swedish study reported that for roads with 90 km/h speed limits and similar alignments, increases in roadway width (carriageway plus shoulders) up to 13 m give significant reductions in accident rates [57]. However, more recent Swedish work concluded that it was not possible to detect any statistically significant differences in accident rates between wide and narrow roads. Of the three road-width classes used (6-8.5 m, 9 m and 10-13 m), the 9 m roads had a higher accident rate irrespective of the decade of construction [58].

There have been a number of studies of the relationship between the shoulder width and the accident rate. However, NCHRP Report 197 [52] concluded that, on tangents, as the shoulder width increases beyond the minimum, the benefit becomes insignificant; on curves, as the shoulder width increases, the accident rate decreases.

As TRB Special Report 214 noted [59], accident rates decrease with increases in lane and shoulder width, and widening the lanes has a greater safety benefit than widening the shoulder. After reviewing more than 30 studies, Zegeer and Deacon [60] made the following conclusions:

- Lane and shoulder conditions directly affect run-off-road (ROR) and opposite direction (OD) accidents. Other accidents types, such as rear-end and angle accidents, are not directly affected by these conditions.
- 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.
- Lane width has a greater effect on accident rates than shoulder width.

- Larger accident rates are exhibited on unstabilized shoulders (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.

Miaou [61] used data on 596 two-lane rural road sections in Alabama, Michigan and Washington to model the relationship between 4,632 single vehicle accidents in 1980-84 and various geometric and traffic traits. He found that increasing lane width by one foot decreases the number of single vehicle run-off-the-road accidents by 14%.

In E. Hauer's [62] review (in a paper prepared during a project for UMA Engineering), it was noted that the tendency of accident rates to decline as lane width increases is not an indication of a cause-effect relationship. The accident rate usually declines as average daily traffic (ADT) increases for a variety of reasons. Narrow roads and lanes tend to be associated with low traffic and therefore with higher accident rates.

Hauer [63] further concluded that several studies suggest that shoulder width is more beneficial to safety at higher traffic volumes than at lower ones, that there is also an indication that roads with wider shoulders tend to have more severe accidents, and that the wider shoulders are associated with fewer run-off-the-road and opposite-direction accidents, which comprise some 40-60% of all accidents. However, wider shoulders may be associated with more of the other accidents.

2.3.3.5 Horizontal curvature

Horizontal curves are one of the most dangerous parts of the rural road network and have attracted a substantial amount of attention in the safety literature. Crash rates on curves are estimated to range from 1½ to four times higher than on tangents [64,65], with an even higher rate of 4½ for truck crashes [66].

In Germany, Steyer et al. [67] noted that nearly half of crashes on non-built-up roads (i.e. rural roads) occurred on curved roadway sections. In the UK, Taylor and Barker [68] found that, of all crashes on rural two-lane roads, 18.5% occurred on curves. Similar rates were found in Denmark, with 20% of all personal injury crashes and 13% of all fatalities occurring on horizontal curves in rural areas [69]. In France, the situation is worse, where 21% of all fatalities occurred on rural curves.

In the Australian State of New South Wales, a reported 48% of all fatal crashes on rural highways occurred either on a curve or on straight road sections where nearby curves were partially responsible for the crash. Of these fatal crashes, 70% occurred on acute curves where the radius of the curve was less than 300 m [70].

Lamm, Guenther and Choueiri [71] noted that at least 30% of the fatalities that occur on the rural road network system in both Germany and the USA occur on curved roadway sections.

Oxley et al. [4] have reviewed international literature with regard to road infrastructure and how it can be improved to reduce the frequency and severity of rural road crashes. There they stated that crashes are more likely to occur on curves than on straight segments of a roadway because of the increased demands placed on the driver and the vehicle. Negotiating a curve constitutes a more difficult driving task than driving along a straight section of road. A vehicle entering or departing a horizontal curve must safely undergo a change in steering angle and a resulting change in side friction forces. Successful curve negotiation, therefore, depends upon the choice of appropriate approach speed, proper deceleration and adequate lateral positioning through the curve. Accordingly, loss-of-control crashes result from an inability to maintain lateral position through the curve because of excessive speed (not corresponding to the alignment of the roadway) and inadequate deceleration in the approach zone. It appears that perceptual factors play an important role in crashes on curves. These factors include poor anticipation of vehicle control requirements on approach and within the curve, limited perception of the demands of the curve, and inadequate appreciation of the degree of hazard associated with a given curve.

There are a number of crash types that are over-represented on curves as compared to tangents. These include: *i)* single-vehicle run-off-road, *ii)* multiple-vehicle collision between vehicles traveling in opposite directions (head-on collision), and *iii)* multiple-vehicle collision between vehicles traveling in the same direction (rear-end collision) [64,72].

Lamm et al. [71] examined the safety criteria for evaluating curved roadway sections with respect to the differences in 85th percentile operating speeds by classifying roadway sections as 'good', 'fair' or 'poor' designs in Washington, USA. They found that the crash rate was highest for horizontal curves in the 'poor' category, with 2.76 crashes per million vehicle kilometers driven; it was lowest for the horizontal curves in the 'good' category, with 0.46 crashes per million vehicle kilometers driven (the crash rate for 'fair' curves was 1.44 crashes/million veh-km). These results suggest that those horizontal curves requiring drivers to make greater speed reductions from the approach tangent are likely to have higher crash rates than horizontal curves requiring lower speed reduction. These findings seem intuitively sound.

Cairney [73] noted that sections with a curvature of between 5-10° have at least twice the crash rate of sections with a curvature of 1-5°, and further that sections with a curvature of between 10-15° have crash rates four times as great. In terms of curve radius, 200 m seems to be the point below which crash rate greatly increases.

Anderson and Krammes [74] examined the relationship between mean crash rate and mean degree of curvature, showing that horizontal curves that require speed reductions had higher crash rates than curves that do not require speed reductions. Curves requiring speed reductions are generally those sharper than about 4°, which corresponds to design speeds less than 100 km/h and estimated 85th percentile speeds less than drivers' desired speeds on long tangents. More specifically, they found that mean crash rates were similar for degrees of curvature from 0.25° to 4°. They described 4° as a breakpoint, after which crash rates increased linearly for the remaining intervals 5° and over. They also noted that when curve sites were grouped into speed-reduction intervals, there was a significant relationship between the interval's mean crash rate and mean speed reduction. In short, the mean crash rate increased approximately linearly with the mean speed reduction.

Council [75] argued that optimally designed curve transitions are an important safety feature, since in approximately 62% of fatal crashes and 49% of injury crashes on curves, the first maneuver in the crash sequence was at the beginning or end of the curve, rather than in the centre.

Lamm et al. [76] noted that the dominant influence on crash rate is curvature change rate. They showed a significant increase in crash and injury risk with increasing curvature change values, particularly for rates with values greater than 200 gon/km (a measure of the absolute sum of curvature change rates), which correspond to radii less than 320 m without regarding transition curves.

The conclusions of studies looking to the relationships between horizontal curves and accidents, especially on two-lane rural roads are as follows [1]:

- A negative relationship has been established between the radius of curve on the one hand and accident rate and accident cost rate on the other.
- Large reductions in the accident rate were noted when comparing very large radii of curves with smaller radii ($R<100$ m).
- A curve of a certain radius found in a sequence of properly balanced curves is safer than an identical curve found within an unbalanced sequence of curves.
- For radii less than 200 m, the accident rate is least twice as high as that for radii of 400 m. Increasing curve radii beyond 400-500 m results in very small improvements in traffic safety.
- For passing through a transition curve (clothoid or spiral) from tangents to circular curves, a safety gain could be observed only for radii of curves less than 200 m. Clothoids provided no safety improvements over direct tangent to circular curve transitions for curves with radii greater than 200 m.

2.3.3.6 Vertical curvature

The literature identified vertical curves as a risk factor for crashes on rural roads. Crests on vertical curves on rural highways can severely restrict stopping sight distance, and there are some reports of increased crash rates at these locations. A study of crashes on vertical curves with limited stopping sight distances was conducted by Fitzpatrick, Fambro and Stoddard [77]. They concluded that the shorter the stopping sight distance, the greater the crash risk, particularly when a major hazard (such as an intersection or sharp horizontal curve) exists beyond the crest. They also concluded that limited sight distance was not the key problem. Rather, it seemed there was a major problem of vehicles stopping in the roadway to make a turn either into a driveway or an access, or turning at an intersection.

Studies cited by Pignataro [78] showed that steeper grades increase the accident rates and skidding accidents on two-lane rural curved sections. Krebs and Kloeckner [1] analyzed accident data for two-lane rural roads in Germany. They indicated that the accident rate showed a slight increase in grades of up to approximately 6 percent. For grades of more than 6 percent, a sharp increase in the accident rates was noted. Studies by the authors indicated that grades of up to 5 percent did not have any particular effect on the accident rate.

An investigation by Glennon, cited by Lamm et al., suggests that grade sections have higher accidents rates than level sections, that steep grades have higher rates than mild grades, and that downgrades have higher accidents rates than upgrades.

2.3.3.7 Sight distance

Sight distance, which is dependent on both horizontal and vertical alignments, is of great importance to traffic safety. In their overview of highway design and traffic safety, Lamm et al [1] summarized recent findings as follows: “Hiersche pointed out that sight distance is the most important criterion in the design of highway alignments. Krebs and Kloeckner did not fully agree with that statement, but said that insufficient sight distances are the cause of many accidents. Meyer, et al. stated that about one-quarter of all rural accidents result from overtaking maneuvers for which passing sight distances were not sufficient. Similar results were reported by Netzer in Germany, who determined that passing maneuvers accounted for about 21 percent of all traffic accidents”.

Another study of accidents on two-lane rural roads in Germany by Krebs [1] and Kloeckner determined the following:

- As sight distance increase, the accident risk decreases.
- High accident rates were associated with sight distance of less than 100 m.

- With sight distances of between 100 m and 200 m, accident rates were about 25% lower than those associated with sight distances less than 100 m.
- For sight distances more than 200 m, no major decreases in accident rates were noted.

A UK study [79] reported that on “clean” sites (i.e. with no accesses, intersections, etc.), there is little erosion of safety resulting from sight distances below an absolute minimum design standard. It was also noted that accident rates rise steeply at sight distances below 100 m.

Nicholson & Gibbons [80] investigated the effects of sight distance on driver speeds on a hilly, winding road alignment in New Zealand. They found that a large proportion of drivers were traveling too fast to stop in the available sight distance, ranging from 44% to 82% over six different sites. Crash numbers were also correlated to the areas where speeds were found to be excessive for the available sight distance. Driver speeds appeared to be influenced more by the level of discomfort experienced while driving around a curve, than by the sight distance restriction.

An analysis of accidents on US roads by Young [1] showed that the accident rate correlated negatively with sight distance. For a sight distance of less than 240 m, the accident rate was twice as high as that for a sight distance of more than 750 m. Sparks also established a negative relationship between stopping sight distance and accident rate in the United States.

2.3.3.8 Traffic volume

The literature indicates that traffic volume is positively correlated with incidences of traffic crashes. As the number of vehicles on a highway increases, the potential for conflicts within a traffic stream also increases.

Milton and Mannering [81] found the positive coefficients of annual average traffic volume (AADT) in the model to indicate that as the number of vehicles through a section increases, so does the number of accidents. They explained that as the number of vehicles increases through a section, the exposure to potential accidents and number of conflicts increases.

Gwynn [82] analyzed crashes and traffic flow on US Route 22 through the city of Newark, New Jersey. Hourly volumes from every day between the years 1959 and 1963 were classified into 100 volume ranges by magnitude. Crash rates were computed and plotted for each of these volume classes, leading to a distinct ‘U’ relationship, with more crashes observed at the higher and the lower traffic volumes. Zhou and Sisiopiku [83] performed a similar study on Interstate 94 in Michigan. This study was slightly different from the previous one, in that it included a volume/capacity ratio instead of the absolute traffic volume. They found a distinct ‘U’ relationship between traffic flow and crash rates.

Qin et al. [84] found that for single vehicle crashes, the marginal crash rate is high at low traffic volumes and low at high traffic volumes, probably because crashes are more likely to involve multiple vehicles at high traffic volumes. Zeeger et al. [85] found that low-volume road accidents are affected primarily by roadway width, roadside hazard, terrain, and driveways per mile. Martin [86] found that incidence rates involving property-damage-only crashes and injury crashes in France are highest when traffic is lightest (under 400 vph), and that the incidence rates are at their lowest when traffic flows at a rate of 1,000 to 1,500 vph. Hadi et al. [87] found that sections with higher AADT levels are associated with higher crash frequencies for all highway types.

Roosmark and Fraek [88] analyzed accident types on roads in Sweden with traffic volumes of up to 11,000 veh/day, and they established that accident rate decreased as traffic volume increased for single-vehicle accidents, while accident rate increased as traffic volume increased for multiple-vehicle accidents.

2.3.3.9 Junctions and accesses

Access density refers mainly to the number of driveways within a roadway segment and is one of the factors singled out as a determinant of accident rates on the highways.

In Spain, Mayora and Rubio [89] concluded that access density is one of the highway variables that has the highest correlation with crash rates in Spain´s two-lane rural roads, and it also influences most the rate of head-on and lateral collisions.

High access density has a negative effect on safety. Therefore preventive safety improvements should include access management and control measures. Ideally, on two-lane rural roads access points should be separated by 2 km. When this cannot be achieved a desirable minimum distance between consecutive access points is 500 m. Although this may not be applicable in access roads, it might be achieved in some higher level highways by applying access management techniques.

Research results deviate from each other by the impact of the number of access points on crash rates. The model developed by Gluck et al. [90] suggests that an increase from 10 access points to 20 access points per mile would increase crash rates by roughly 30 percent. Papayannoulis et al. [91] related traffic safety to access spacing, and presented results from eight states. They found that most studies report 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 points per mile.

In their review of published literature on issues and topics related to rural road safety, Hamilton and Kennedy [92] stated there are several different factors associated with increased accident frequency at rural dual carriageway junctions. These included the number of vehicles entering and leaving the main road at grade-separated junctions, minor road traffic flow at T-junctions, vertical alignment issues, and issues associated with gaps in the central reserve. They found that the accident frequency was decreased by increasing the distance between junctions, providing a wide verge on the off-side of slip roads, and/or increasing on-slip merge lengths.

2.4 Interactive highway safety design model (IHSDM)

Technology has been having an important effect on the geometric design of highways. During the past 30 years, highway design has moved from the drafting board to the computer, as computer-aided design (CAD) systems have been implemented by most highway agencies and design consultants. The nearly universal use of CAD systems for highway design provides an opportunity to ensure better consideration of the operational and safety effects of geometric elements in the proposed designs for highway projects. To accomplish this, computer tools are needed that work interactively with CAD systems, and that allow users to evaluate the operational and safety effects of geometrics. Federal Highways Administration (FHWA) has been developing a first-generation system of this type, known as the Interactive Highway Safety Design Model (IHSDM). The IHSDM software was initially developed when a deficiency was recognized in checking road compliance with federal, state, and local policies. A need was also recognized to determine road users' comprehension of road designs in their driving practices [93].

The official FHWA [94] description of the IHSDM is "a suite of software analysis tools for evaluating safety and operational effects of geometric design decisions". IHSDM's goal is to provide transportation engineers with a tool that will help them design safe two-lane rural highways. The initial development effort focused on two-lane rural highways, with the first public release in 2003. IHSDM has also been designed to allow for local customization to suit various jurisdictions.

IHSDM consists of several analysis modules, to assess different aspects of highway designs (discussed further in Chapter 5) [94], namely:

- A Policy Review Module (PRM), to verify compliance of designs with specified national/state highway design policies and guidelines;
- A Crash Prediction Module (CPM), to estimate the number and severity of crashes on specified roadway segments;
- A Design Consistency Module (DCM), to provide information on the extent to which a roadway design conforms to drivers' expectations (especially speed profiles);
- A Traffic Analysis Module (TAM), to estimate via traffic simulation the operational effects of road designs under current and projected traffic flows, e.g. travel times, time spent following, and vehicle interactions;
- A Driver/Vehicle Module (DVM), to estimate drivers' speed and path choice along a roadway and subsequent measures including lateral acceleration and friction demand;

- And an Intersection Diagnostic Review Module (IRM), which uses an expert system to evaluate intersection design alternatives, and suggest countermeasures to safety problems.

2.5 German road safety models

2.5.1 Network safety management (NSM)

Network safety management (NSM) comprises of a methodology to analyze existing road networks from the traffic safety point of view. The methodology is based on the Empfehlungen für die Sicherheitsanalyse von Straßennetzen ESN [95] (German Guidelines for Safety Analysis of Road Networks) and was published in 2003. Considered together with the "traditional" safety methods, black spot management and safety inspections, there are now three pillars for road safety work in Germany. While the two traditional methods aim at small-scale considerations, the ESN has been developed to evaluate whole-road networks, e.g. federal, state, county or municipal networks [96,97]. The main idea behind the concept is to compare each road section of a road network, in terms of the current safety performance, as measured by Accident Cost Densities (ACD), compared to the Basic Accident Cost Densities (bACD). The difference between ACD and bACD reveals the safety potential of these sections. A ranking of sections on the basis of this safety potential allows a well directed appropriation of resources to those sections with a higher need of safety improvements [98]. It will in other words highlight the parts of the network where most can be gained in relation to the cost. Identification of high-risk road sections or black spots may be done to target action on stretches of road where high numbers of fatal and severe accidents happen or can be expected (for more details, see section 4.4 and 4.8).

Once such high-risk road sections or black spots have been dealt with, the safety quality of the whole network may be improved. Assessments could range from identifying and treating accident patterns at single high-risk sites or black spots to understanding and managing safety over whole routes [99,100].

The application of ESN on the German motorway network reveals that 90% of all accident costs occur in just 10% of the network length.

2.5.2 Road safety audits

In 1999 the German Ministry of Transport, Building and Housing decided to start establishing road safety audit procedures. Within less than three years the Road and Transport Research Association developed audit procedures and published the Guideline for Road Safety Audits in 2002 [96]. Training courses for auditors and regular meetings of auditors were also established. Road Safety Audits are leading to an improvement of road design and thus are able to enhance road safety. Furthermore, experience from the Road Safety Audits is being used for the further development of design standards in Germany.

Once a road design has been chosen, possibly dangerous road elements can be identified and rectified to ensure that no safety requirement had been underestimated in the previous planning. Road Safety Audits provide the tools and proficiency for identifying possible mistakes before the road is cast in concrete. Introducing early improvements and corrections at the planning and design stages may allow the social and economic costs of accidents to be reduced [100].

2.6 Other safety models

+ *EuroRAP* is the European Road Assessment Programme for rating road-related crash risk in an attempt to mobilize government action through community demand. It systematically tests risk on roads, awards star safety ratings, and identifies problems that can be addressed by practical road improvement measures. This programme began in 2000 and is led by the AA Foundation for Road Safety Research, based in the UK [101].

EuroRAP information is useful at several levels. First, it will generate consumer information, providing road users with information about the relative risk of roads and understanding of the features that make roads safe or dangerous. For instance, a ‘risk rate’ map has been published for selected road sections in England, presenting the color coded crash risk bands from ‘low’ to ‘high’, with road sections in black having a risk rate more than 10 times higher than those colored in dark green. The ratings highlight road sections where there is a lack of appropriate balance between the speeds at which a vehicle might be involved in a crash, the protection provided by the road, and vehicle designs minimizing the severity of any resulting injury [102,103].

Secondly, it provides important messages for road designers and planners. It demonstrates where the deaths and severe injuries occur on the road network and can initiate more detailed analyses of crashes. It also provides a strategic view of the safety of routes and what to do about what causes injuries on these routes. It will also show how and where measures must be implemented to increase crash protection, separate vehicles moving in opposite directions, reduce conflicts where possible, and provide investment in other elements that improve the safety of the road [4,100].

Thirdly, it provides important information for government agencies, on which to base their strategies. For instance, the information can be used to balance vehicle design, road engineering and behavior crash reduction priorities, to promote the understanding of crash and injury risk, and to select appropriate speed limits for roads [103].

+ In Europe, the *SAFESTAR* (Safety Standards for Road Design and Redesign) project is a research study focusing on traffic safety for what is known as the “Trans-European Roadway Network” (TERN) that links the major European centers. The aim is to develop safety standards for highway design and redesign on all classes of road involved [104]. Nine European research institutes are collaborating on SAFESTAR, with the Institute for Road Safety Research (SWOV, Netherlands) coordinating these activities. Of the eight priority areas being investigated, two of particular relevance are “cross-sections of rural roads” and “design of curves in rural roads”, and working papers have been produced documenting the institutes’ findings to date [105,106]. Although the project does not include the specific development of road safety models, the literature review has identified a large number of relationships developed in the past from which to produce guidelines of best practice.

+ The Finnish National Road Administration (FinnRA) evaluates yearly traffic safety improvement targets using a program called *TARVA* (named after the Finnish words meaning Evaluation of Safety Effects Using Effect Coefficients). Introduced in 1995, TARVA uses crash models together with crash history to estimate the expected number of crashes on the road if no measures would be implemented. The effects of measures can then be evaluated using a standard set of incidence and severity reduction factors for different treatments. Relatively simple relationships, largely based on vehicle exposure, are used primarily to estimate average risk for homogenous road sections. More complex models are also available if necessary, including sight distances, road widths, etc. FinnRA found that, when combined with historical crash data, more complicated models did not significantly improve the prediction effects [107].

+ In November 2004, the *IMPROVER* project (Impact Assessment of Road Safety Measures for Vehicles and Road Equipment) [108] was carried out by the Federal Highway Research Institute of Germany (BASt) together with 14 partner institutes. IMPROVER project is a study commissioned by the European Commission (Directorate General Energy and Transport) to examine the following aspects of road safety: the impact on road safety, emissions and fuel consumption by the increasing use of sports utility and multipurpose vehicles; the impact assessment of measures improving the road safety of light vans; the impact of cruise control on traffic safety, energy consumption and environmental pollution; and the harmonization of road signs and road markings from a safety point of view.

According to the tasks the project is divided into four subprojects:

Subproject 1: Impact on road safety due to the increasing of sports utility and multipurpose vehicles

The objective of this study was to gain insight and understanding of the safety and environmental issues for Sport Utility Vehicles (SUVs) and Multi-Purpose Vehicles (MPVs) on the European road network. National statistics from countries participating in the project were collected and analyzed for the rates of accident involvement of SUVs during recent years, and the injury outcomes associated with these accidents. It was shown that there is a slightly higher problem with SUVs in collisions with other road users as compared to collisions between other passenger cars. Based on expected fleet changes in the near future, this problem can however become more serious. There are no distinctive trends observable for the MPV car category. This study has shown that both geometrical incompatibility and stiffness/mass incompatibility appear to be factors in the accidents observed [109].

Subproject 2: Impact assessment of measures concerning the improvement of road safety of light goods vehicles (LGV)

The increasing participation of light goods vehicles (LGV) in road traffic, especially considering the growth of courier and express services, is of growing concern for road safety in recent years. In the last years, both the number of LGVs and their participation in accidents increased, and moreover the highest total number of fatalities is found on rural roads. The term LGV as used in this report means a commercial vehicle used for the carriage of goods with a maximum weight of more than 1 t and less than 3.5 t.

To enhance the road safety performance of LGVs a set of scenarios with different road safety measures was developed to be tested by means of cost–benefit analysis: speed limiters (no ISA-technology); an electronic stability program (ESP); social rules (using digital tachographs); seat-belt wearing rate (using seat-belt reminders or seat-belt locks); professional fleet safety management (using accident data recorders); licensing rules (increasing the minimum age of drivers to 21 years); and professional driver education and training.

The cost–benefit analysis (CBA) yielded a B/C ratio greater or equal to 1 for *i)* a professional driver training programme, *ii)* devices to increase seatbelt wearing, and *iii)* the electronic stability program, ESP, thereby indicating that these three safety systems are economically justified for light goods vehicles. The B/C-ratio for ESP is better than the results of other measures under consideration. Therefore, ESP should be encouraged as standard equipment for LGV [110].

Subproject 3: Impact of cruise control on traffic safety, energy consumption and environmental pollution

In this subproject, the impact of cruise control (CC) was analysed with respect to traffic safety, energy consumption, and environmental pollution.

The subproject discovered no major safety, energy consumption or environmental pollution issues with respect to CC. However, several areas of possible concern were noted. Based on these areas of concern, recommendations for actions at an EU level were proposed.

It seems likely that cruise control in some form will become more widespread in vehicles in the EU in future years. The work undertaken here has shown that there are many knowledge gaps and issues of possible concern. In contrast to the more complex adaptive cruise control ACC, little research has been done specifically on CC [111].

Subproject 4: Harmonisation of road signs and road markings on the TERN from a safety point of view

This report shows the possibilities for improving traffic safety on the Trans European Road Network (TERN) by harmonisation of fixed traffic signs and road markings in EU countries. The study first focused on the differences in road signing between EU countries, and then assessed the effect of these differences on traffic safety from the viewpoint of costs and benefits. Thereafter, the work developed four harmonization scenarios. Finally, institutional analysis was undertaken to elucidate the implementation steps and EU actions for harmonization [112].

The total number of fatal accidents on the TERN was estimated to be almost 5,000 per annum, along the length of the TERN, which is approximately 70,000 km. The harmonization of road signing and markings among EU countries could well prevent a lot of road deaths on the TERN by means of the following scenarios, actions and recommendations:

Scenario 1: they should be harmonised in the short term

The first scenario showed harmonisation of relatively low cost measures that could be realised in the short term. The first estimation of the measures showed that the safety benefits should exceed the costs within one year. An efficient way of involving road signing to improve traffic safety on the TERN could be to harmonise the use of:

- exit lane countdown marker signs to all motorway exits and intersections;

- retro-reflective road markings on the whole of the TERN;
- and better pre-trip information on the World Wide Web about the existence and meaning of various road signs and road markings for motorists in Europe.

The European Commission should start the implementation of these measures as soon as possible because the means to carry them out are quite clear-cut. The necessary steps in this scenario would be the drafting of a document that would result in a decision that would allow implementation of the Scenario 1 measures immediately, as well as the completion of the detailed list of roads (or road sections) that belong to the TERN, in order to make it better identified and known in every EU country.

Scenario 2: they should be harmonised in the short term if the means are available

The second scenario consisted of urgent harmonisation needs, but the exact means for harmonisation will not be known until further work and research are undertaken. The task of driving safely on the TERN would be supported by the harmonised use of:

- E-road numbers (only on E-roads which cross at least one border and at their intersections);
- and exit numbers on motorways.

These could be realised by means of adding ‘patches’ of numbers to the existing signs in the first instance (costing around 1,600,000€ according to first rough estimation).

Scenario 3: they should be harmonised in the long term

The third scenario involved long-term measures, as the estimated costs of harmonisation exceed the estimated safety benefits likely to be obtained in a single year. However, the harmonisation need is high-priority and safety would improve through:

- extending the use of profiled road markings;
- and improving night-time visibility of road markings.

Both of these should be applied to road sections with high accident rates (only the accident types on which these road markings might have an effect need to be considered) in the first instance.

The aim is *(i)* to prevent accidents due to fatigue, and *(ii)* to enhance drivers' ability to keep to their lane and to enhance optical guidance especially in the dark.

Scenario 4: they could be harmonised in the long term

The fourth scenario comprised a variety of details in road signage and markings among EU countries. Their safety effects were not assessed to be high separately, but together they demonstrate the clutter and inconsistency that foreign drivers have to face on the TERN. Under this scenario, 14 aspects of road signing differences among EU countries were identified, which require harmonisation along the TERN. Thus, the combined effect of harmonisation of these differences may be higher as it meets the general demand for the continuity and uniformity of road signing on the TERN in the long term.

After making an initial assessment, the commission should develop particular issues further by launching further work and research into the measures suggested in Scenario 4. Other than that, no specific action is to be undertaken in the short term.

2.7 Chapter summary

The literature review presented in this chapter has provided some important basic background information for the topic of traffic safety and for the issues related to accident characteristics, causation, models and rates.

The literature reveals that IHSDM makes the evaluation of highway design significantly easier and faster. Each module focuses on a specific area of analysis. The policy review module automates the current process of checking a design against applicable, quantitative design guidelines. The crash prediction module provides quantitative safety performance measures, including expected crash frequency and severity. The remaining modules diagnose factors contributing to safety performance of the highway design. It appears pragmatic, however, to investigate further the IHSDM model and to look at how to adapt it for use in Germany.

3 Data Collection

3.1 Introduction

The purpose of this chapter is to describe the process of data collection in the research. The following sections describe a database of rural roads that was compiled to summarize state routes in the rural areas of the study region, North Rhine Westphalia (NRW). The database was comprised of 470 segments of 157 different state routes, covering nearly 250 kilometres of rural roads. Data requirements included the highway segment geometry (horizontal alignment, vertical alignment and cross-section, roadside geometry, and traffic volume data), and accident data.

The study region in North Rhine Westphalia contains the Wuppertal, Solingen and Remscheid Kreisfreie Städte, and Landkreis Mettmann areas, as is shown in Figure 3.1.

3.2 Selection of the representative segment

The choice of many two-lane rural road segments was supported through the findings of the accident studies which were conducted in North Rhine Westphalia. There the minimum length of each road was 0.4 km, and it was at least 0.8 km from city limits, eliminating the effects of controlled speed environments. Many of the investigated sites consisted of horizontal curves with sag, crest, and level vertical curves, while other investigated sites consisted of straight roadways with sag, crest, and level vertical curves.

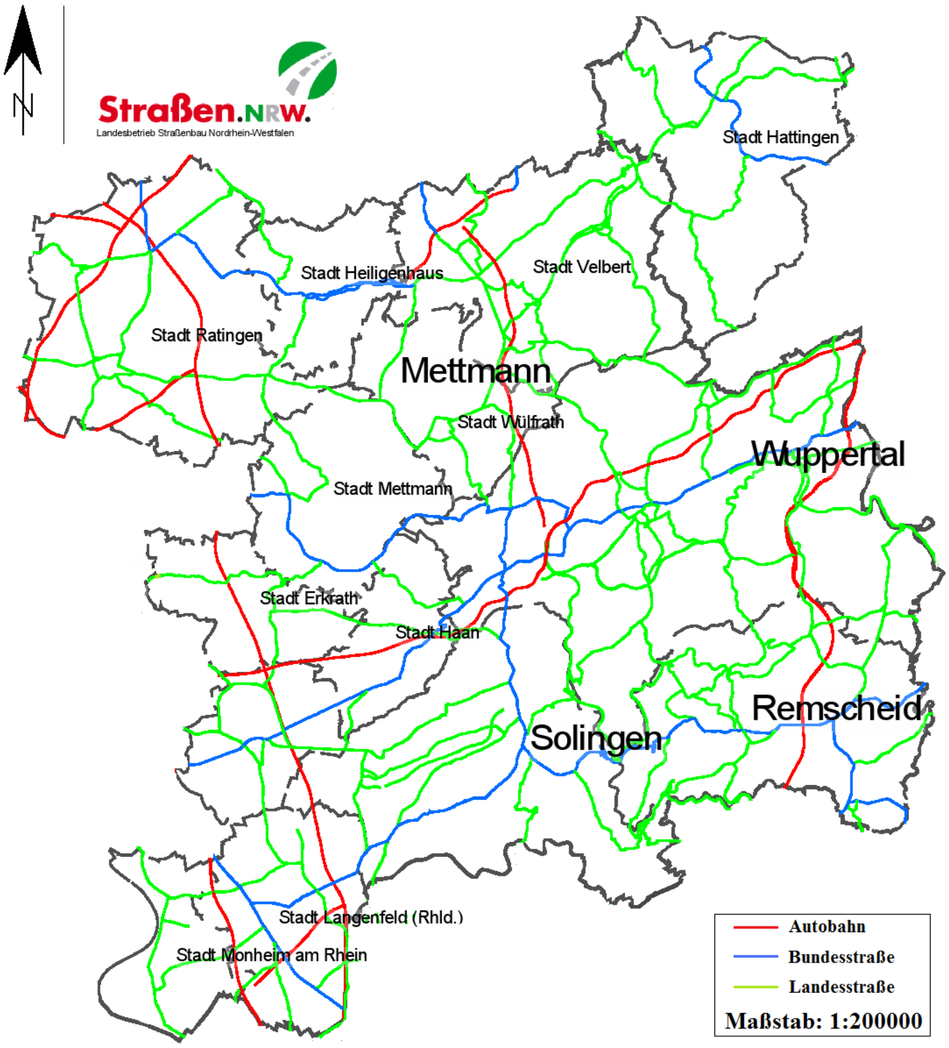


Figure 3.1: Map of study region (adapted from NWSIB) [113].

The project was divided into individual highway segments with a minimum length of 0.4 km. New highway segments began at points 75 m before and after the center of each intersection to avoid intersection related accidents, and also began at each point where the value of one of the following characteristics changes [114,115] :

- average daily traffic volume (ADT) (<500, 500-2000, >2000) veh/day;
- lane width (Lw) (<3.0, 3.0-3.5, >3.5) m;
- shoulder width (Sw) (<1, 1-2, >2) m;
- shoulder type (St) (turf, gravel, paved);

- driveway density (DD) (<3, 3-8, > 8) driveway /km;
- roadside hazard rating (RHR) (<2, 3- 5, >7), a 7 point categorical scale from 1 (best) to 7 (worst) [116];
- and grade (g) (= 0, 1-4, > 4) %.

In addition, a new highway segment starts at any of the following locations:

- beginning or end of a horizontal curve;
- beginning or end of a passing lane, in either direction of travel, or a short three- or four-lane section provided for the purpose of increasing passing opportunities;
- or beginning or end of a center two-way left-turn lane (TWLTL).

3.3 Resources

The study began by collecting data from the computer-based sources of Strasseninformationsbank Nordrhein-Westfalen NWSIB [113]. Purchased from Landesbetrieb Strassenbau Wuppertal, highway segment geometry and roadside geometry data were extracted from 2003 videotapes for North Rhine Westphalia. Accident data was obtained from kreispolizeibehoerde Mettmann and Polizeipraesidium Wuppertal. In addition, the traffic data was collected from electronic records of Landesbetrieb Strassenbau Essen for the years 1990, 1995 and 2000.

3.3.1 Video logs

The video-logs were used to investigate potential roadway design and traffic operations issues that might have contributed to an accident. The video-logs are still photographs taken in both directions at regular intervals from the right-most lanes of the roads maintained by the state. The video-logs provided by Landesbetrieb Strassenbau Wuppertal from 2003 were used to find information such as walkway, crosswalks, shoulder type, roadside, auxiliary lane, bridge characteristics, and driveway. The main advantage of using the video-logs was their limiting the need for site visits. Figure 3.2 shows snapshots of the video log viewer.

Figure 3.2: Pictures from the video snapshots viewer.

3.3.2 Police reports

The police report for an accident is a brief outline which gives information including the date and time, the location of the accident, the vehicles involved, vehicle information as well as driver, passenger and pedestrian (if involved) information, a summary of the accident and accident scene diagram, and the final rest positions of the vehicles. These reports have various codes for the vehicle type, alcohol and drug use, safety equipment used, severity level, road conditions at the time of accident, traffic control devices present, contributing causes concerning the driver/pedestrian and other similar information, all of which is intended to aid officers in explaining the accident events.

In this study, kreispolizeibehoerde Mettmann provided accident reports in electronic form (Excel files) for the period of 2000-2005, while Polizeipraesidium Wuppertal reports for 2002-2004 were obtained as paper copies.

3.4 General data categories

The databases have been used for the analysis consisting of highway segments and accident data.

3.4.1 Highway segments data

Highway segments contain all non-intersection geometric data elements, including the horizontal and vertical alignments, cross-section, roadside and traffic volume.

3.4.1.1 Horizontal alignment

The horizontal alignment is the centerline of the highway, consisting of geometric elements and descriptors, i.e. tangent elements, circular and spiral curve elements, headings, deflections and coordinates. The length of a horizontal alignment is measured in stations, with units of meters. A station equation element is provided to account for discontinuities in the stationing of the horizontal alignment.

3.4.1.2 Vertical alignment

The vertical alignment is the profile of the highway surface, containing tangent and curve elements. The vertical alignment can be modeled either using the vertical point of intersection (VPI) element and a single "elevation" at any point along the alignment, or through the vertical tangent/curve elements and a single "elevation" at any point along the alignment.

All vertical curves are parabolic and may be symmetrical or asymmetrical. Both sag and crest curves can be represented.

3.4.1.3 Cross-section

A cross-section is the offset view of the highway. It includes elements to describe the cross-slope, lane width, and the shoulder slope and width.

Lanes are represented in two main categories: through lanes and auxiliary lanes. The auxiliary lane category includes climbing lanes, turn lanes, two-way left-turn lanes, and passing lanes.

3.4.1.4 Roadside

Roadside elements are the constructs parallel to the highway lanes in the horizontal and vertical dimensions, and beyond the shoulders in the offset dimension. Roadside elements include foreslope, ditch, backslope, obstruction offset (distance to sight obstruction), bike facilities, driveway density, and roadside hazard rating.

3.4.1.5 Traffic volume

The traffic data needed is: flow rate (veh/h); annual average daily traffic volume (veh/d); percentage of recreation vehicles in traffic stream; percentage of trucks in traffic stream; and design speed, posted speed, operating speed and desired speed.

In some cases, if one type of traffic volume data is available but the process requires a different type (e.g. DHV is required, but the user only has AADT), the required data can be estimated from the available data.

3.4.2 Accident data

The accident data which has been collected for this research included the accidents that occurred on the road segments over the six-year study period (2000-2005) in Landkreis Mettmann and the three-year study (2002-2004) in Wuppertal, Solingen and Remscheid Kreisfreie Städte.

Accident data extracted from the case study sites was used to validate the IHSDM model; these are described further in Section 5.6.1. Every accident has been categorized into the following severity levels [117]:

- Fatal accident (F): an accident resulting in the death of one or more persons;
- Serious injury accident (SI): an accident in which one or more persons were seriously injured and were taken to hospital for in-patient treatment (of at least 24 hours);
- Light injury accident (LI): an accident in which one or more persons were slightly but not seriously injured;

- or Property-damage-only accident (PDO): an accident in which no one is killed or injured but which resulted in damage to the vehicle/s and/or other property.

The severity of an accident was assigned according to the highest injury severity sustained by an occupant involved in the accident. For instance, if there is at least one fatality resulting from an accident, then it was defined as a fatal accident and when there is at least one serious injury but no fatal injuries then it was classified as a serious injury. Likewise, no evident injuries were reported it fell into the no injury category.

The accidents were also been classified depending on type:

- single-vehicle accidents, including overturned, ran-off-road, parked and animals accidents;
- or multiple-vehicle accidents, including head-on, right-turn, left-turn, rear-end, angle and sideswipe accidents.

In the data-extraction process, the recorded accidents which were related to drivers falling asleep or a mechanical defect in the vehicle, or which were bicyclist or pedestrian related, have all been excluded.

The default IHSDM crash severity and accident type proportions are based on the Highway Safety Information System (HSIS) data [118]. A similar analysis of accident types was undertaken using the Germany injury and non-injury accident data from included case study sections (excluding intersection accidents) in the research database.

It should be noted that the IHSDM data includes three levels of injury accidents (incapacitating, non-incapacitating, and possible) whereas the German data has only two injury levels (serious and light) [119]. It appears that light accident numbers in Germany compare well with the combined proportion of non-incapacitating and possible injury accidents. For simplicity, the proportion of possible injury accidents for German data has been set to zero, with the other two injury levels assumed to match their German equivalents. Property-damage-only accidents are assumed, by definition, to equate to Germany's non-injury accident data. The accident data in Germany was equated to IHSDM categories. Table 3-1 summarizes the key linkages between the two categorization systems.

Table 3-1: Equivalency of accident types between IHSDM and Germany [118,119].

IHSDM accident type	Germany accident type equivalent assumed
Single-vehicle accidents	
Collision with animal	Animal struck codes of 751 (wild) or 752, 753 (domestic)
Collision with parked vehicle	Accident Type 5 codes 50, 54, 55, 56, 57, 58, 59 or 70, 71
Overturned + Ran-off-road	Accident Type 1 codes (loss of control) or 76, 77
Other single-vehicle collision	Single-vehicle accidents not already coded elsewhere, 199, 73
Multiple-vehicle accidents	
Angle collision	Accident Type 2 codes 26, 271 or Accident Type 3 codes 30, 31, 32, 33,35
Head-on collision	Accident Type 6 codes 661, 68, 66 or 52
Left-turn collision	Accident Type 2 codes 20, 21, 281 or 72
Right-turn collision	Accident Type 2 code 23
Rear-end collision	Accident Type 6 codes 60, 61, 62 or 742
Sideswipe collision	Accident Type 6 codes 63, 64, 65 or 25 or 51
Other multiple-vehicle collision	Multiple-vehicle accidents not already coded elsewhere, 299 or 399

4 Data: Analyses and Evaluations

4.1 Introduction

This chapter discusses the statistical analyses performed on the data to determine which characteristics were correlated to roadway safety aspects, including geometric characteristics, accident rate and severity, and collision type. The data collected were analyzed using Microsoft Office Excel 2007 and Statistical Package for the Social Sciences (SPSS® 16.0, 2007).

4.2 Data accidents comparison

4.2.1 Comparison between obtained accidents data and reported values in annual reports

The errors of the accident data collected were estimated by a comparison between obtained surveyed accidents and reported values, as found in the Annual Report 2005, der Landrat Als Kreispolizeibehoerde Mettmann and in Annual Report 2003, Polizeipraesidium Wuppertal [120,121]. During 2005, a total of 13,547 traffic accidents with 10.2 % of accidents outside of the city (i.e. in a rural region) were reported by the police in Landkreis Mettmann. In Wuppertal, Solingen and Remscheid Kreisfreie Städte, 21,465 accidents were reported in the whole region (urban and rural roads) during 2003.

Referring to the accident severity percentage distributions in Table 4-1, the proportions of data obtained for accidents and the reported values are convergent, but there are some differences between the proportions in Wuppertal, Solingen and Remscheid Kreisfreie Städte, due to the data being cumulative for all roads (i.e. including no individual data for rural roads).

When looking at the data for accidents overall, there appears to be a low error level in the data collection.

Table 4-1: Accident severity percentage distributions of obtained accidents data and reported values.

Accident Severity	**Landkreis Mettmann**		**Wuppertal, Solingen and Remscheid Kreisfreie Städte**	
	Obtained data in 2005,%	**Reported data[*] in 2005,%**	**Obtained data in 2003,%**	**Reported data[+] in 2003,%**
Fatal, F	0.2	0.1	0.7	0.1
Serious Injury, SI	4.0	3.0	4.4	1.7
Light Injury, LI	12.6	12.6	11.0	9.1
Property Damage Only, PDO	83.2	86.2	84.0	89.1

[*] for rural region
[+] for urban and rural regions

4.2.2 Comparison between obtained accidents data and reported values in "quantification of road safety effects of different construction, design and operational forms on rural roads"

A truly integrated investigation was carried out by the German Road Research Labortary (Bundesanstalt für Straßenwesen, BASt): the project "Quantification of road safety effects of different construction, design and operational forms on rural roads" [122]. Between 2002 and 2006, different types of cross-sections were investigated, including approximately 53,926 sections (47,959 km) of two-lane, three-lane and four-lane roads in Bayern, Brandenburg, Nordrhein Westfalen and Rheinland Pfalz states. The general aim of the research project is to develop a basis for quantification of road safety effects that have different forms of construction, design and operation on rural roads. Therefore accident rates and accident cost rates were determined for rural roads regarding different forms of construction and operation. These accident parameters were determined distinguishing between sections with no influence from intersections, sections near to intersections and intersections themselves.

The most important results of this survey for the rural road sections of 9,112 km (with no influence from intersections) were that the total accidents numbered 31,349. Moreover, approximately 30% of these accidents were fatal and serious injuries. However, 70% of these accidents was type 1 and type 6 in comparison with 6% and 50% for obtained accidents data in this case study, as shown in Tables 4-2 and 4-3.

From the tables below, it can be seen form the reported data that the wider cross-section has a higher accident severity, and a lower accident rate and accident cost rate. There was also a reduction in the percentage of run-off accidents (type 1) and an increase in the percentage of turn accidents (type 2+3).

Table 4-2: Accident severity percentage distributions of obtained accidents data and reported values for the different cross-sections.

Cross-section, m	**Obtained accidents data 2000-05**				**Reported values 2002-06**			
	F, %	**SI, %**	**LI, %**	**PDO, %**	**F, %**	**SI, %**	**LI, %**	**PDO, %**
5.00	0	5.7	13.7	80.6	2	23	48	27
5.50	0	8.0	11.7	80.3	3	29	44	24
6.00	0.6	6.7	12.5	80.2	4	27	46	24
6.50	0.8	7.6	14.6	77.0	4	27	45	25
7.00	0.8	4.9	12.4	81.9	4	28	46	22
7.50	0.4	4.5	14.3	80.8	4	24	51	22
8.00	0.2	5.0	11.8	83.0	5	26	48	21
8.50	0.3	5.0	11.8	83.0	5	25	51	19
All	*1*	*5*	*13*	*81*	*4*	*25.2*	*47.8*	*23*

F=Fatal, SI=Serious injury, LI= Light injury, PDO= Property damage only.

Table 4-3: Accident type percentage distributions of obtained accidents data and reported values for the different cross-sections.

Cross-section, m	**Accident type*, %**							
	Obtained accidents data 2000-05				**Reported values 2002-06**			
	Type 1	**Type 2+3**	**Type 6**	**Rest**	**Type 1**	**Type 2+3**	**Type 6**	**Rest**
5.00	18.9	12.7	39.6	28.8	63	10	21	7
5.50	24.5	18.1	42	15.4	62	11	18	9
6.00	23	24.3	21.7	31	58	11	22	9
6.50	24.4	29.6	26.5	19.5	51	17	23	9
7.00	20.9	31.2	24.2	23.8	40	22	27	11
7.50	29	28.3	19.2	23.5	42	24	24	10
8.00	16.3	26	35.3	22.3	33	26	29	12
8.50	31.2	27.6	24.4	16.8	32	27	28	13
All	*23.2*	*27.2*	*26.6*	*23*	*45.1*	*19.1*	*25.2*	*10.6*

* Type 1(Run-off), Type 2 (Left-turn+Right-turn), Type 3 (Angle), Type 4 (Pedestrians), Type 5 (Parked), Type 6 (Head-on+Rear-end+Sideswipe), Type 7 (Animals+Others).

Table 4-4: Accident rate and accident cost rate distributions of obtained accidents data and reported values for the different cross-sections.

Cross-section, m	**Obtained accidents data 2000-05**				**Reported values 2002-06**			
	No. of acci.	**Traffic volume, veh/d**	**AR, acci/(10^6 veh*km)**	**ACR, €/(10^3 veh*km)**	**No. of acci.**	**Traffic volume, veh/d**	**AR, acci/(10^6 veh*km)**	**ACR, €/(10^3 veh*km)**
5.00	212	4908	2.24	55.32	1125	1264	0.69	55.4
5.50	188	3609	2.36	63.11	1917	1570	0.65	63.4
6.00	480	5682	1.83	47.39	5414	3020	0.62	57.4
6.50	487	5743	2.14	53.72	3896	3825	0.48	44.4
7.00	1015	7332	1.73	42.44	2701	5216	0.37	35.8
7.50	890	10041	1.91	36.46	5322	5418	0.37	31.5
8.00	838	10745	1.39	27.66	3639	8442	0.25	23.8
8.50	340	10334	1.69	26.10	557	8765	0.25	23.2

Thus, in comparison with this case study's results, it can be seen from the obtained data that the wider cross-section have lower accident severity and lower accident rate and accident cost rate. Moreover there was a significant variation in run-off accidents percent (type 1) and turn accidents percent (type 2+3).

4.3 Data analysis approach

Descriptive statistics for collected accidents data are given in Appendix I, and the graphical analyses of accidents severity and collision type are plotted in Figures 4.1 and 4.2, respectively.

4.3.1 Results of accidents severity

In Figure 4.1, the data for accident severity is represented; almost 81% of accidents that occurred on the road segments were property-damage-only accidents. Additionally, close to 13% of all accidents were categorized as light injury. Less than 5.5% were serious injury, and of all road segments examined, only 20 accidents were fatal, accounting for 0.5% of all accidents. Injury accidents as a whole, however, still accounted for nearly 19% of all accidents (compared with 40% for all out-city roads in Germany, as shown in Table 1-1), thus justifying the need to reduce the severity of accidents.

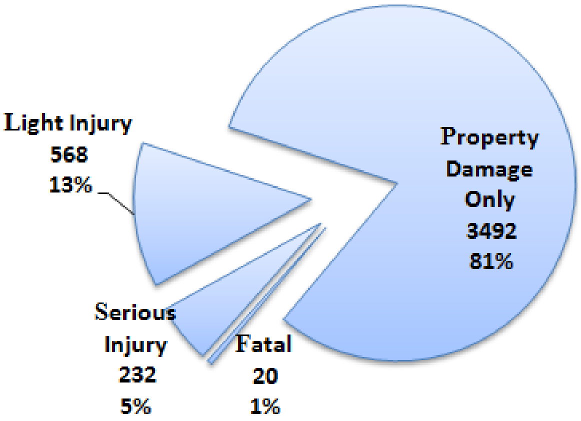


Figure 4.1: Accidents distribution by severity.

4.3.2 Results of accident types

The collision types desired for the analysis include head-on, rear-end, parked, run-off, animals, angle, left-turn, right-turn, sideswipes, and others. These collision types were calculated as percentages of the total number of accidents, and were then illustrated in Figure 4.2. The accident types are based on IHSDM categories. This is only an issue for comparison purposes. For more details see section 5.6.1.

Travel on rural roads usually occurs at high-speeds. Run-off accidents mostly involve vehicles leaving the roadway and colliding with rigid objects or overturning. It is common for errant vehicles to strike roadside trees, poles, embankments or a variety of man-made structures. Vehicles overturn when roadsides are uneven, too steep, or both. Accidents in which vehicles overturn or strike roadside hazards tend to result in severe injuries, because of the rigid nature and often narrow dimensions of the objects struck, as well as the high impact speeds. As mentioned in the literature review, run-off-road accidents account for between 15 and 53% of all road accidents in the USA, depending on the area studied, the type of road, and the time of day.

As be shown in Figure 4.2, for all rural two-lane road stretches involved, around one fourth of the accidents (23 percent) are run-off-road.

Also, Figure 4.2 indicates that both left-turn and right-turn accidents are 25% of the total accidents. The other categories of collision, namely head-on, rear-end, parked, animals, angle, sideswipes and others, make up the rest of the accidents percentage.

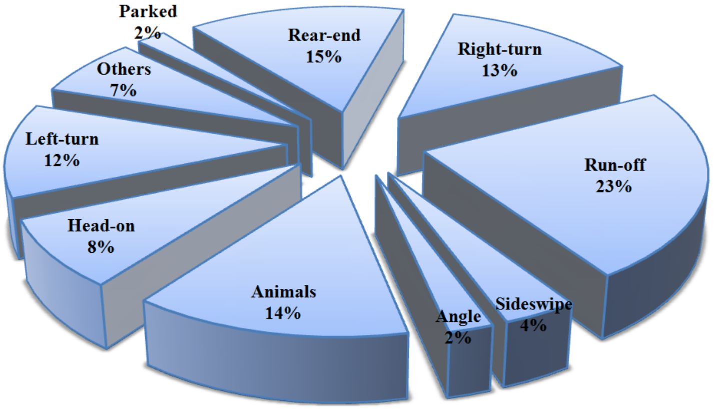


Figure 4.2: Accidents distribution by type.

4.3.3 Relation of accidents severity and types

To explain the relationship between accident severities and types, a matrix is applied, in which rows and columns represent the accident severity and collision types respectively. As shown in Figure 4.3, run-off accidents have a higher severity than the larger proportion of fatal and injury accidents, as compared to other collision types. As demonstrated by the relevant literature, single-vehicle accidents are common on the rural road network, and they typically involve vehicles leaving the roadway and colliding with fixed objects on the roadside or overturning. These accidents generally result in serious injuries (in Canada, at least one third of all fatal and other casualty accidents in rural areas involved single vehicles running off the road). Unlike many of the other accident types, run-off-road accidents are caused by a wide variety of factors. The most common reason that vehicles leave the road is the driver's failure to control the vehicle [123].

Both accident type and severity on rural roads differ from those on urban roads. While accident rates are generally higher in urban areas (because of the greater number of intersections and higher traffic volumes), accidents on rural roads tend to be more severe (because of the greater speeds and diversity of road conditions) [4]. Accidents involving a single vehicle striking a fixed object or a vehicle rollover are more prevalent in rural areas than urban areas [124]. The major contributing factor to the high number of run-off accidents is high speeds, so we are focusing on attempts to control and reduce speeds. To achieve this objective, higher speeds are eliminated to preserve safety [125].

Moreover, the low population density and geographic isolation of rural communities can increase detection, response, and travel time for emergency medical services, thereby reducing accident survivability [126].

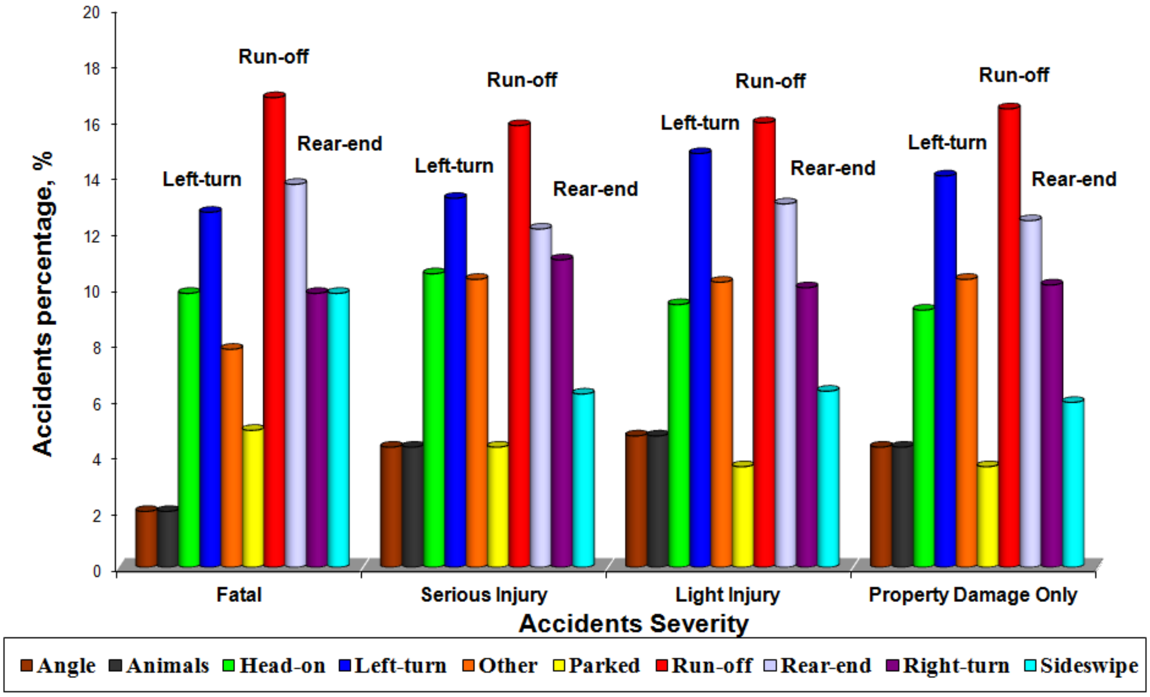


Figure 4.3: Matrix of accident severity and types.

4.4 Correlation analysis

The correlation coefficient measures the degree of the linear relationship between two variables. This value can also be viewed as the strength of the linear relationship. It takes values from -1 to 1. A value of 0 means that there is no linear relationship between the two variables. Positive values of the correlation coefficient indicate that the two variables tend to be both large or both small at the same time. Negative values indicate an inverse relationship.

4.4.1 Independent variables

Independent variables, or explanatory variables, include those characteristics of the road segments that have possible correlation with safety (or dependent variables). It was important to consider as many characteristics as possible at the onset, to be able to properly account for any variables influencing the accident histories of the segments. Independent variables collected in this database included lane width, driveway density, roadside hazard rate, radius, grade, 85th percentile speed, and traffic volume. Correlation coefficients were calculated for each pair of variables to determine if the use of any variable was redundant. Table 4-5 shows the correlations between all of the independent variables collected.

Through the cross-correlation of variables, a high degree of correlation between two variables can result in the relationship between some variables and crashes not being reported correctly in the model. When two variables are correlated, the addition of the second variable to the model may show a weak relationship with crashes, whereas the first variable might have a strong relationship. In some instances, the second variable may show a totally different relationship with crashes (e.g. a negative rather than positive relationship) because of the correlation. Typically, it is best to choose only one of two highly correlated variables for a model.

None of the independent variables showed substantially high positive or negative correlation to each other, which means that all independent variables have been considered in the analysis. The closest correlation coefficient to +1 or -1 occurred between the categorical variables for lane width and traffic volume and was only a value of 0.444, which is shown in bold-face font in Table 4-5 for emphasis.

Table 4-5: Correlation between geometric characteristics (independent variables).

	Lane width	**Driveway density**	**Roadside hazard rate**	**Radius**	**Grade**	**85th % speed**	**Traffic volume**
Lane width	1	-0.016	0	0.068	-0.051	0.235	**0.444**
Driveway density		1	-0.073	0.050	0.026	0.049	-0.093
Roadside hazard rate			1	-.0155	0.029	-0.203	-0.072
Radius				1	-0.031	0.431	0.077
Grade					1	-0.009	-0.053
85th % speed						1	-0.052
Traffic volume							1

4.4.2 Dependent variables

Dependent variables, or response variables, include those characteristics of a road segment that were believed to be the result of the various roadway characteristics identified in section 4.4.1. While a precise cause-and-effect relationship may not be known, a correlation can be shown between various characteristics of the data and the dependent variables. The dependent variables obtained for this database included accident rates, severity, and collision types.

The correlation coefficients between geometric characteristics variables and accidents rates, severity, and collision types are illustrated in Tables 4-6, 4-7 and 4-8, respectively.

Among the variables depending of the geometry of the highway, the 85th percentile speed and traffic volume have the highest correlation with accident rates, while individual alignment element characteristics (lane width, driveway density, radius, grade, and roadside hazard rate) yield much lower correlation coefficients (see Table 4-6).

Table 4-6: Correlation coefficients between geometric characteristics and accidents rate.

	Lane width	**Driveway density**	**Roadside hazard rate**	**Radius**	**Grade**	**85th % speed**	**Traffic volume**
AR	-0.108	-0.009	0.085	-0.145	0.065	**-0.262**	**-0.257**
ACR	-0.143	-0.007	0.056	-0.051	0.032	**-0.225**	**-0.253**
AD	0.124	-0.091	0.029	-0.102	0.019	-0.109	**0.264**
ACD	0.004	-0.066	0.044	-0.083	0.088	**-0.179**	0.075
SAPO	-0.207	-0.016	0.075	-0.113	0.0	**-0.283**	**-0.407**

According to Table 4-7, the 85th percentile speed is the characteristic with the highest correlation with fatality and serious injury accidents in two lane rural road segments. When considering these results it is important to bear in mind that the correlation coefficient is only a measure of the level of association between the variables, but does not prove a causal relationship.

Table 4-7: Correlation coefficients between geometric characteristics and accidents severity.

	Lane width	**Driveway density**	**Roadside hazard rate**	**Radius**	**Grade**	**85th % speed**	**Traffic volume**
F	-0.002	-0.054	0.001	-0.006	-0.049	**-0.065**	-0.035
SI	-0.075	-0.008	0.007	-0.035	-0.004	**-0.139**	0.005
LI	0.067	-0.003	-0.047	-0.049	-0.048	0.006	**0.196**
PDO	0.086	-0.042	-0.013	-0.061	-0.019	-0.071	**0.319**

Table 4-8 shows that traffic volume is associated with three types of accidents, and rear-end accidents showed the highest correlation with traffic volume of all the highway variables included in the study.

Table 4-8: Correlation coefficients between geometric characteristics and accidents type.

Accidents type	**Lane width**	**Driveway density**	**Roadside hazard rate**	**Radius**	**grade**	**85th % speed**	**Traffic volume**
Angle	**.201**	-.147	-.053	.018	.012	.052	.101
Head-on	**-.344**	.053	-.058	-.095	.090	-.296	-.142
Animals	-.036	-.081	-.097	**.200**	.053	.103	.043
Parked	.193	.122	-.073	.042	**-.229**	.057	.041
Other	-.013	-.083	.012	-.038	-.051	.026	**.142**
Run-off	.067	-.143	.037	-.136	**-.167**	**-.167**	-.021
Left-turn	.056	**.131**	.027	.053	-.019	.007	-.026
Rear-end	.087	.056	-.059	.009	-.063	.102	**.431**
Sideswipe	.171	-.009	-.168	-.212	-.051	.140	**.247**
Right-turn	.047	-.139	.219	-.175	-.004	**-.229**	-.063

As can be seen the correlations are relatively low, because there is a relatively high dispersion of the data. This was expected, since accidents happen as a result of numerous and different factors, with each factor contributing differently to the occurrence of an accident. Moreover, these factors and their relative contribution typically change from one accident to another.

4.5 The association between road geometrical design elements and accident characteristics

Regression analysis is used in the study and dependent and independent variables were therefore determined. The number of accidents that happened in two-lane rural roads and the accident rates found by using ADT values are taken as dependent variables.

The analysis shows that there are obvious relationships between traffic accidents and some road geometric design elements.

Although it has been shown in different studies that the relationship between accident rates and traffic volumes is not linear, in multivariate regression analysis of accident rates, traffic volume should be considered as an independent variable. This is for the purpose of finding the variables with highest association with accident rates, and the lack of linearity observed in the relationship was not considered to be decisive.

The traffic volume strongly influences the traffic flow and consequently the frequency and severity of accidents. A detailed, controlled investigation of the direct effect of traffic volume would be difficult, since the specific traffic volume at the time of an accident is generally unknown. Therefore, only the average daily traffic (ADT) can be related to accident history.

As shown in the Figure 4.4, for multiple-vehicle accidents, the accident numbers increased as traffic volume increased. In contrast, there was a reduction in the accidents number with increasing traffic volume. Also, the relationship between accident rate and traffic volume was a U-shaped curve. A fall in the rate up to a traffic volume range of 15,000-16,500 veh/d was followed by an increase for higher traffic volume ranges. This relationship was also confirmed by several investigations [1]. In Germany, Lamm reported for traffic volumes of up to 10,000 veh/d that accident rate decreased as the traffic volume increased.

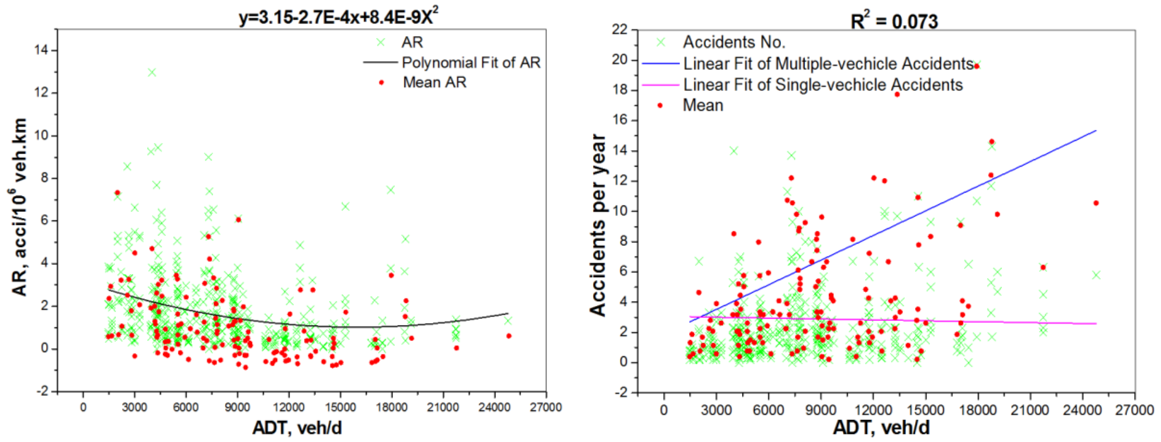


Figure 4.4: Traffic volume (ADT) relationship with the accidents rate and number of accidents.

Vertical alignment is the inclination of a roadway, expressed as a percent of grade. In the study area, 75% of the sections were level and 3% of the sections had a steep slope greater than 5%. Figure 4.5 indicates that there is a positive relationship between the grade and the accidents rate, and the R-squared value indicates that 40% of the relationship can be attributed to the grade. Also, grades have relatively little effect on the accident rate, whereas a sharp increase in accident rate was noted on grade 5 and 14%.

Similar results were reported by Krebs and Kloeckner (cited by Lamm [1]) in Germany, where it was indicated that grades of up to 5% did not have any particular effect on the accident rate.

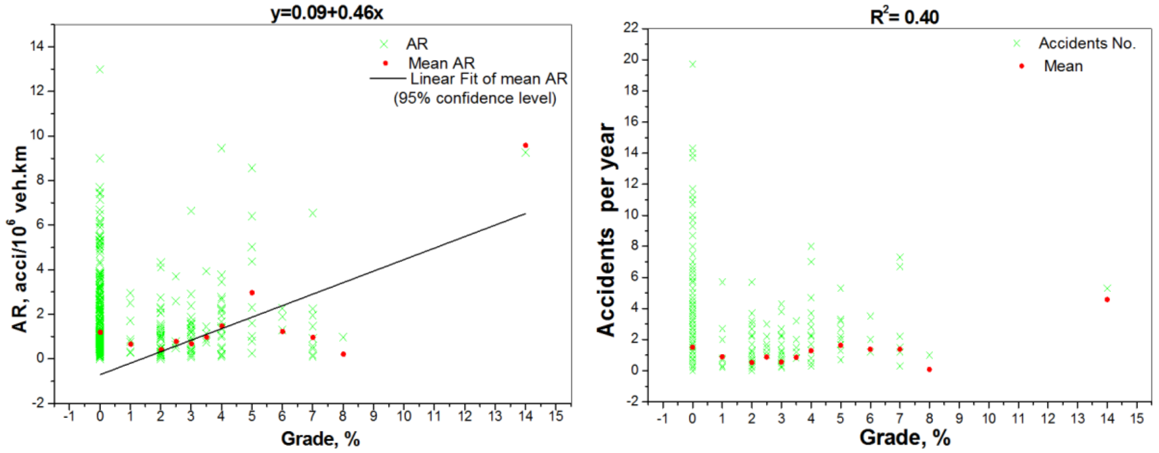


Figure 4.5: Grade relationship with the accidents rate and number of accidents.

As outlined in Chapter 2, past research has generally shown that there is a positive relationship between the number of access points per kilometer and the accident rate on a roadway. Figure 4.6 shows that the relationship is slightly positive with a coefficient determination of 3%.

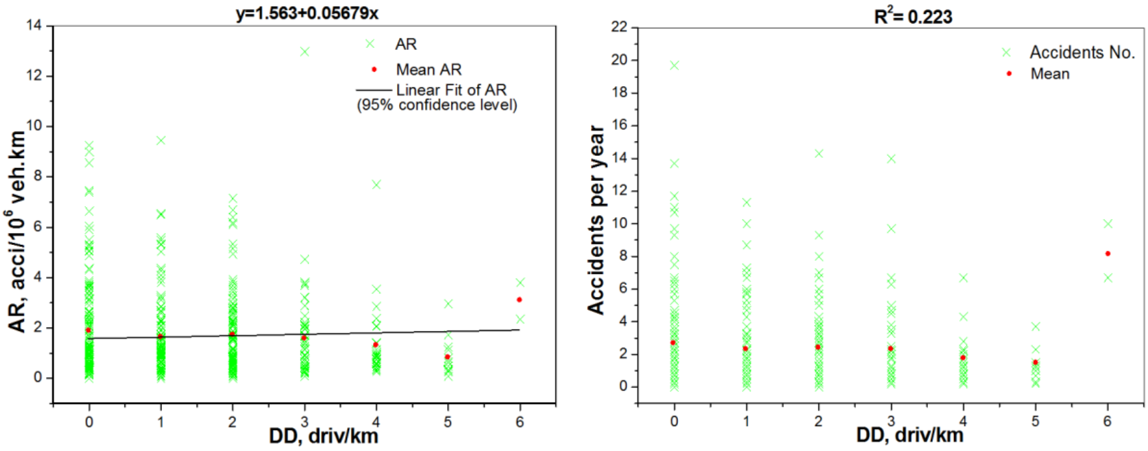


Figure 4.6: Driveway density (DD) relationship with the accidents rate and number of accidents.

The roadside hazard rating is a subjective measure of the hazard associated with the roadside environment. The rating values indicate the accident damage likely to be sustained by errant vehicles on a scale from 1 to 7. The ratings are determined from a 7-point rural pictorial scale [116], as shown in Appendix II. A value of 1 refers to a low likelihood of an off roadway collision or overturn. A value of 7 refers to a high likelihood of an accident resulting in a fatality or severe injury. The data collectors selected the rating value that most closely matched the roadside hazard level for the accident sites.

Figure 4.7 shows that the ratings of roadside hazard generally ranged from 5 to 7 along the sections and has a positive relationship with accident rate. Among the limited significant geometric features of the sites, roadside hazards increase the severity of the single vehicle accidents.

Regarding German guidelines for the design and evaluation of cross-sections for rural roads [127] (Richtlinien für die Anlage von Straßen, Teil: Querschnitte RAS-Q 96), the minimum lateral clearance outside the paved carriageway must be one meter (with respect to RHR this is rating 7). The results in providing a safety margin have to be kept clear of solid obstacles.

When used, crashworthy barrier systems over extended lengths of high-speed rural roads have the potential to reduce fatal and serious injuries to the occupants of errant vehicles by around 90%, with conservatively estimated BCRs of around eight. Flexible barrier systems can address two major rural crash categories, namely single-vehicle and head-on accidents, on straight or curved road sections, without the need for costly road duplication and/or geometric improvements to rural infrastructure [128].

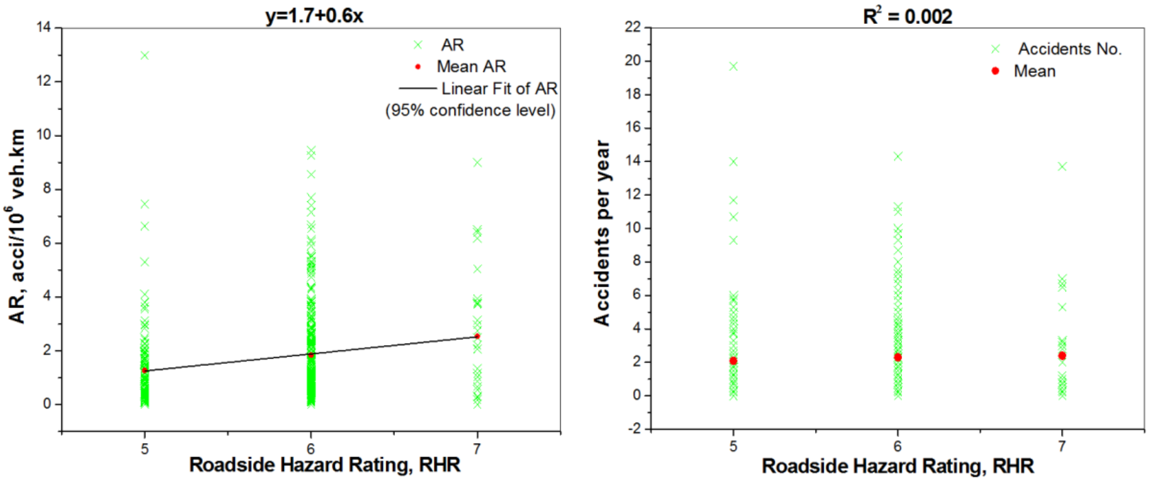


Figure 4.7: Roadside hazard rating relationship with the accidents rate and number of accidents.

The analysis of results generally agrees with the engineering intuition that wider lanes result in reduced accidents. Roads with lanes of 4 m or wider have lower accident rates than roads with 3 m lanes, which is again intuitively expected. This is illustrated in Figure 4.8. It should be noted that most two-lane roads in the rural study have a lane width less than 3 m (80%).

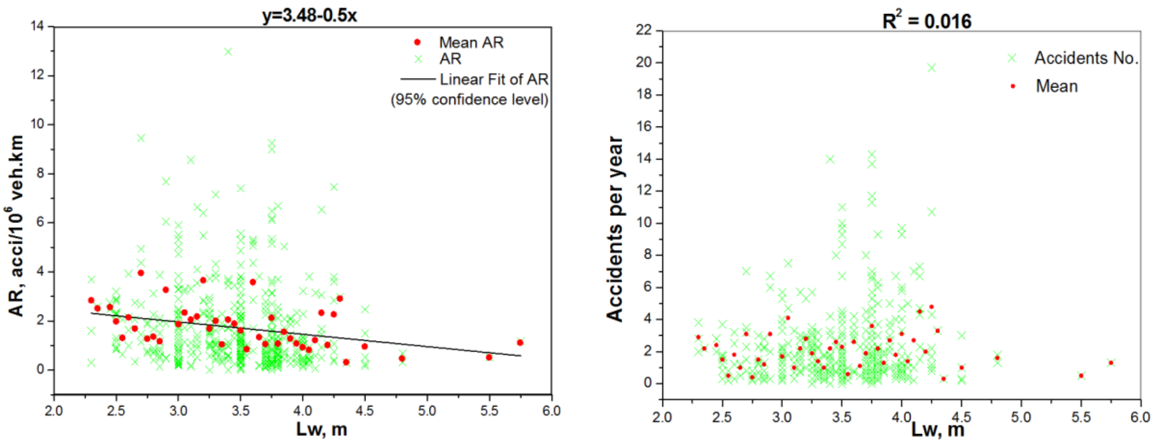


Figure 4.8: Lane width (Lw) relationship with the accidents rate and number of accidents.

Horizontal curves are one of the most dangerous parts of the rural road network, and have attracted a substantial amount of attention in the safety literature. In Germany, Steyer et al [129] noted that nearly half of accidents on non-built-up roads (i.e. rural roads) occurred on curved roadway sections. In the study area, where 57% of sections contain curves, 90% of accidents occurred on horizontal curves sections because of increased demands placed on the driver and vehicle. It is clear that curves were significantly responsible for the accident.

The average radius expresses the sharpness of curves that drivers typically encounter on a given section of the roadway. A large average radius would indicate curves that are typically not sharp and it would be expected that lower accident rates would exist on these types of curves. In contrast, a curve with a small average radius indicates that the curves are quite sharp and higher accident rates would be expected in these conditions.

As shown in Figure 4.9, the data indicates continually increasing accident rate with decreasing radius. This increase in accident rate becomes particularly apparent at curve radii less than 500 m (a cross-point in safety) and it is stable for radius more than 850 m (very small improvements in traffic safety), which agrees closely with previous results.

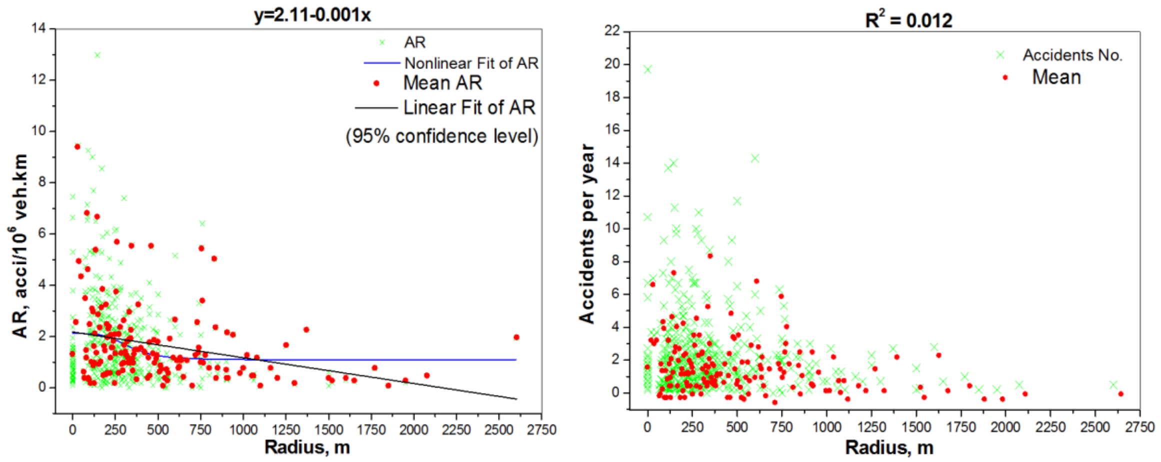


Figure 4.9: Radius relationship with the accidents rate and number of accidents.

4.6 Network safety management NSM

Network Safety Management (NSM) is a methodology to analyze existing road networks from the traffic safety point of view [98,99]. The methodology is based on the Empfehlungen für die Sicherheitsanalyse von Straßennetzen ESN [95] (German Guidelines for Safety Analysis of Road Networks).

In NSM, the key parameter to assess the safety performance of road sections is the so-called safety potential. The safety potential describes the potential savings in accident costs that could be reached by remedial measures. It is defined as the amount of accident costs per kilometre road length that could be reduced if a road section would have a better practical design. Safety potential is calculated as the difference between the actual accident cost per kilometre and the basic accident cost per kilometre that could be expected if that section would have design characteristics matching investment decisions on reconstruction planning [130].

The aim of NSM is to enable road administrations to [99,131]:

- determine sections within the road network with a poor safety performance based on accident data and where deficits in road infrastructure have to be suspected;
- and rank the sections by potential savings in accident costs in order to provide a priority list of sections to be treated by road administrations.

The accident structure of the sections are then analyzed in order to detect abnormal accident patterns, which can lead to possible improvement measures. Finally, this offers the possibility of comparing the costs of improvement measures to the potential savings in accident costs, allowing the ranking of measures by their cost–benefit ratio.

4.6.1 Basic Values for determination of safety potentials

4.6.1.1 Accident costs

When analyzing accidents of different categories together, the numbers of accidents are weighted by the accident severity. Accident costs (AC) are, therefore, used to describe the combined effect of number and severity of the accidents.

- Annual average accident cost AC_a [€/year]

$$\mathrm{AC_a(F + SI + LI + PDO)} = \frac{\mathrm{A(F)\times MCA(F) + A(SI)\times MCA(SI) + A(LI)\times MCA(LI) + A(PDO)\times MCA(PDO)}}{\mathrm{t}} \qquad (4\text{-}1)$$

where A is number of accidents (acci), MCA is the mean cost per accident (€/acci) and t is the period of time under review (year).

Table 4-9 shows the mean cost per accident for four different levels of severity in rural roads (in North Rhine Westphalia, NRW) as provided by Bundesministerium für Verkehr, Bau und Stadtentwicklung BMVBS [95] (German Federal Ministry of Transport, Building and Urban Affairs).

Table 4-9: Mean costs per accident for various severities [95].

Severity Description	Cost per Accident [€/acci]
Fatal + Serious Injury	230,000
Light Injury	18,000
Property Damage Only	7,000

Price level 2000

4.6.1.2 Densities

Accident densities (AD) and accident cost densities (ACD) describe the average annual number of accidents and the overall costs incurred to the economy by accidents occurring over a 1 km length of a road section. The density can be calculated as the ratio of the annual number of accidents with respect to accident costs and the length of the road section over which the accidents occurred.

- Accident density AD [acci/(km.y)]

$$\mathrm{AD} = \frac{\mathrm{A}}{\mathrm{L} \times \mathrm{t}} \tag{4-2}$$

- Accident cost density ACD [1000 €/(km.y)]

$$\mathrm{ACD} = \frac{\mathrm{AC}}{1000 \times \mathrm{L} \times \mathrm{t}} = \frac{\mathrm{AC_a}}{1000 \times \mathrm{L}} \tag{4-3}$$

where L is the length of road section (km). The density is thus a measure of the (length-specific) frequency at which accidents have occurred during a specific period over a specific road section.

4.6.1.3 Rates

The kilometrage-related accident figures of road sections are given by accident rates and accident cost rates.

- Accident rate AR [acci/(10^6 veh.km)]

$$\mathrm{AR} = \frac{10^6 \times \mathrm{A}}{365 \times \mathrm{ADT} \times \mathrm{L} \times \mathrm{t}} = \frac{10^6 \times \mathrm{AD}}{365 \times \mathrm{ADT}} \tag{4-4}$$

where ADT is the average daily traffic in t years (veh/d).

- Accident cost rate ACR [€/(1000 veh.km)]

$$\mathrm{ACR} = \frac{1000 \times \mathrm{AC}}{365 \times \mathrm{ADT} \times \mathrm{L} \times \mathrm{t}} = \frac{10^6 \mathrm{ACD}}{365 \times \mathrm{ADT}} \tag{4-5}$$

Accident rates (AR) describe the average number of accidents along a road section per 1 million vehicle kilometers traveled. Accident cost rates (ACR) describe the corresponding average cost as the result of road accidents which have occurred along this road section per 10^3 vehicle kilometers traveled.

4.6.1.4 Safety potentials

It is an important task of road administrations to determine the road sections that have poor safety properties which could be improved by changes in the roadway, its equipment, and traffic operation.

As resources are limited, those sections where improvements can be expected to have the highest cost–benefit ratio have to be treated first. Therefore, information is needed on the accident costs per kilometer (or at a given location) and the safety potentials for possible remedial measures [99,131,132].

The safety potential (SAPO) is defined as the amount of accident costs per kilometer road length (cost density) that could be reduced if a road section would have a best-practice design. The higher the safety potential, the more societal benefits can be expected from improvements to the road.

- Safety potential SAPO [10^3 €/ (km.y)]

$$\mathrm{SAPO} = \mathrm{ACD} - \mathrm{bACD} \qquad (4\text{-}6)$$

The basic accident cost density (bACD) represents the anticipated average annual number and severity of road accidents (represented by the accident costs) per kilometer, which can be achieved by a best-practice design at the given average daily traffic (ADT). It can be calculated as the product of basic accident cost rate (bACR) (35 €/1000 veh.km) as assigned by the Bundesministerium für Verkehr, Bau und Stadtentwicklung BMVBS [95] and the average daily traffic [97]:

- Basic accident cost density bACD [10^3 €/(km.y)]

$$\mathrm{bACD} = \frac{\mathrm{bACR} \times \mathrm{ADT} \times 365}{10^6} \qquad (4\text{-}7)$$

In ideal circumstances the basic accident cost rate (bACR) required for determining the safety potential contains no influence from the infrastructure on the accidents. Rather, it represents the accident cost rate caused only by the other two components of the transport system: vehicles and road users.

The advantage of the safety potential compared to the classic accident parameters is that it allows assessing different road types and roads with different volumes at the same time. Furthermore, as the safety potential is given in accident cost, it can be related to the cost of the improvement measures.

Accident costs are used instead of accident numbers also because this allows for a weighting of accident numbers by accident severity. Accident costs are usually calculated by multiplying the number of accidents of each category with the related, nationally calculated mean cost per accident [99].

4.6.1.5 Ranking of sections

The sections of the road network are ranked on the basis of the magnitude of safety potential. As a result ranking is obtained for those sections in the road network with a particularly high need for improvement and particularly high improvement potential. This then forms the basis for a detailed study in order to determine possible improvement measures [95,98,99]. The distribution of safety potentials of the road sections in form of a map is shown in section 4.7.1 (Figure 4.12). The results of the analysis are presented in diagrams and Figure 4.10 gives a chart showing the road sections with the highest safety potentials within the network under the study.

The detailed analysis of the accident structure is carried out individually for the section with a huge safety potential (rank no. 1). The aim of this analysis is to understand the dysfunctions of the road before implementing counter-measures. This enables solutions to be adapted to the specific nature of each road encountered.

Where an improvement of the infrastructure is expected to be highly cost efficient, suitable measures can be derived from a comprehensive analysis of the accidents. The safety potential and the calculated cost of the measure form the basis for an economic assessment, which is usually conducted as a cost–benefit analysis.

Therefore, only the described NSM methodology provides all the necessary information for an objective assessment of road safety and an establishment of a ranking of sections for further analysis and treatment. This allows the limited resources to be spent in the best way to improve road safety for the whole society.

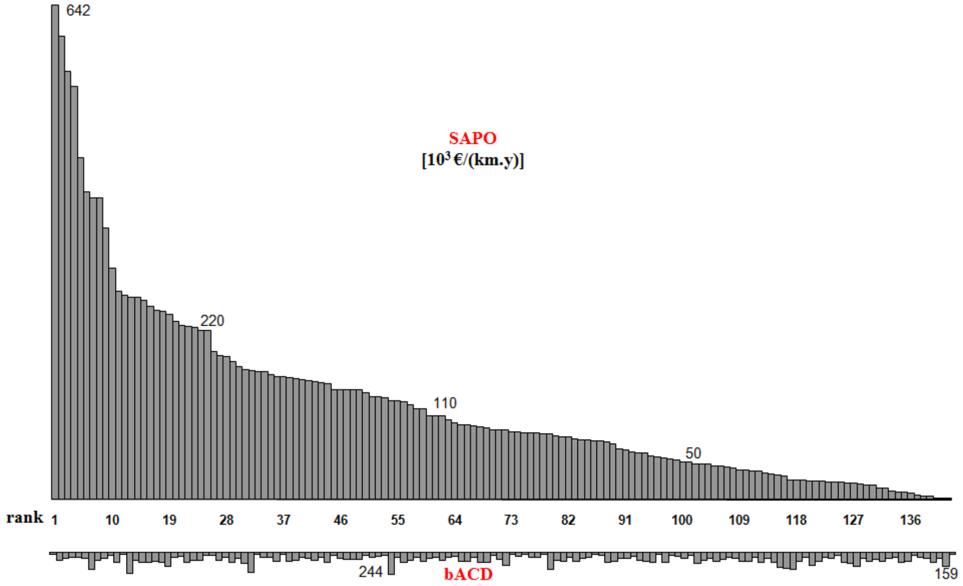


Figure 4.10: Chart of road sections with the highest safety potentials within the network under study.

Detailed analysis of the huge safety potential section

In Velbert, section B227-18 had a huge safety potential (642 10^3 €/ (km.y)). Throughout this section (of 1.1 km) over 6 years (2000-2005) with a traffic volume of 2000 veh/d, the accidents analysis showed that:

- there were 26 accidents (8 serious injuries, 3 light injuries and 15 property damage only);
- there were three accidents type (50% head on, 35% run-off and 15% animals);
- and the accident rate was 10.8 acci/(10^6 veh*km) and accident density was 7.9 acci/(km.y).

As illustrated in Figure 4.11 (the overall site plan), there are many curves with radii <200 m and some as low as 25 m, and the worst roadside with lane width 3.0 m.

Based on the detected conspicuous accident patterns and its analysis, suitable measures for the improvement of the road infrastructure shall be derived. Concluding from the accident types, major effort should be put into preventive actions against these accidents.

- The counter-measures that make a fundamental improvement to the inherent safety of rural roads, with respect to head-on accidents, include the use of crashworthy barrier systems on medians, or separating opposing vehicle directions along undivided rural roads. Due to the difficulty in predicting where head-on accidents will occur, crashworthy barrier systems should be installed over extended lengths of the roadway.
- Counter-measures against run-off accidents can be made by erecting crashworthy roadside and/or guardrail barriers over extended lengths of the roadway, because of the extreme difficulty in preventing a substantial number of drivers and riders from leaving roadways, and by improving roadside slopes and other hardware.
- The principal infrastructure solutions for head-on and run-off accident types include delineation of centre- and edge-lines to improve vehicle lane-keeping, especially on curves, and applying the rumble strip along edge- or center-line to alert drivers when they drift from their lane.
- Geometric improvements to curves have the potential to substantially reduce the incidence of head-on and run-off accidents.

Once a high-risk road section has been dealt with, the safety quality of the whole network may be improved. Assessments could range from identifying and treating accident patterns at a single high-risk section to understanding and managing safety over whole routes.

Finally, the efficiency of the countermeasures should be assessed. This then makes it possible to compare the potential savings in accident costs with costs for counter-measures in order to rank measures by their priority.

4.7 Accidents risk assessment algorithm

This section focuses on integrating the mapping and statistical techniques that are widely adopted in accident analysis research, in order to develop a systematic algorithm to assess accident risk. The algorithm involves a combination of a mapping technique (NSM) and statistical methods (cluster analysis). GeoMedia Professional is used to locate accidents on a digital map and show their distribution. Cluster analysis is used to group the homogeneous data together [133].

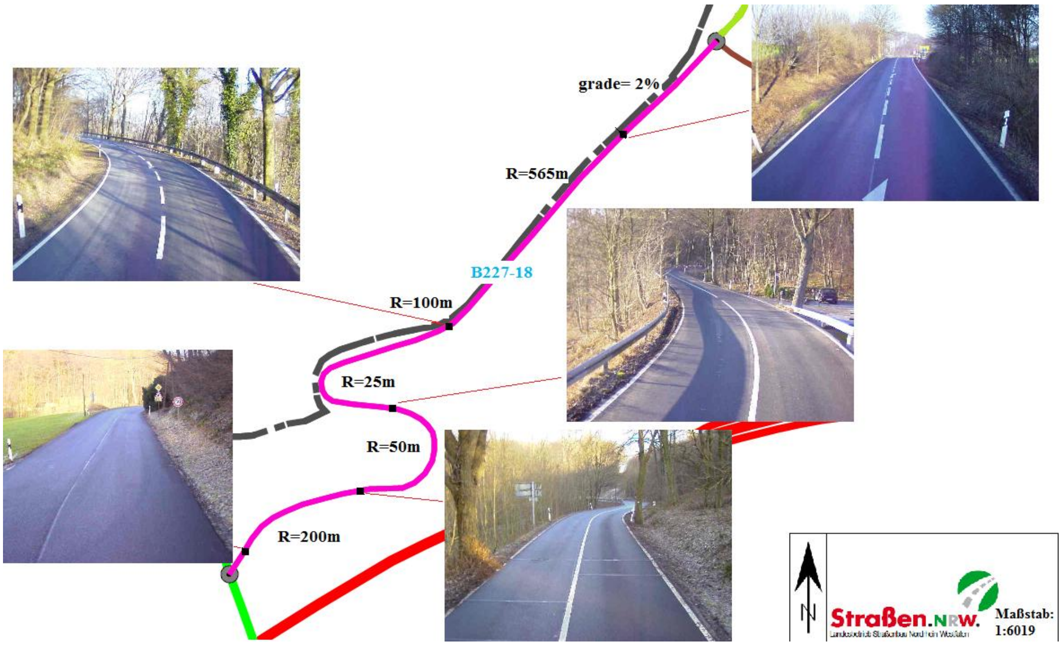


Figure 4.11: Plan of section B227-18[113].

4.7.1 Database mapping

The accident databases are linked up and stored in the database of the GeoMedia Professional software using the NSM method. This is completed by importing the accident data into the digital map by selecting the same coordinate system. The accident database contains information such as geometric design elements, accident characteristics and locations.

The objective of mapping is presenting the data in ways that can determine which treatments are appropriate. We have mapped data for two-lane rural roads in Landkreis Mettmann and Wuppertal, Solingen and Remscheid Kreisfreie Städte, as shown in the Figures below.

Regarding Figure 4.12, the map of accidents rate distribution (upper left map) highlights that the high accident rate (>=4 acc./mio veh.km) is concentrated in Velbert, Wuppertal and Remscheid cities. Green represents the lowest rates, yellow a middle range, and then red and black for the roads that have the highest rates. Based upon the geographical distribution of the accident cost rate, the region is clustered into three groups. The illustration of the cluster analysis result is explained in next section.

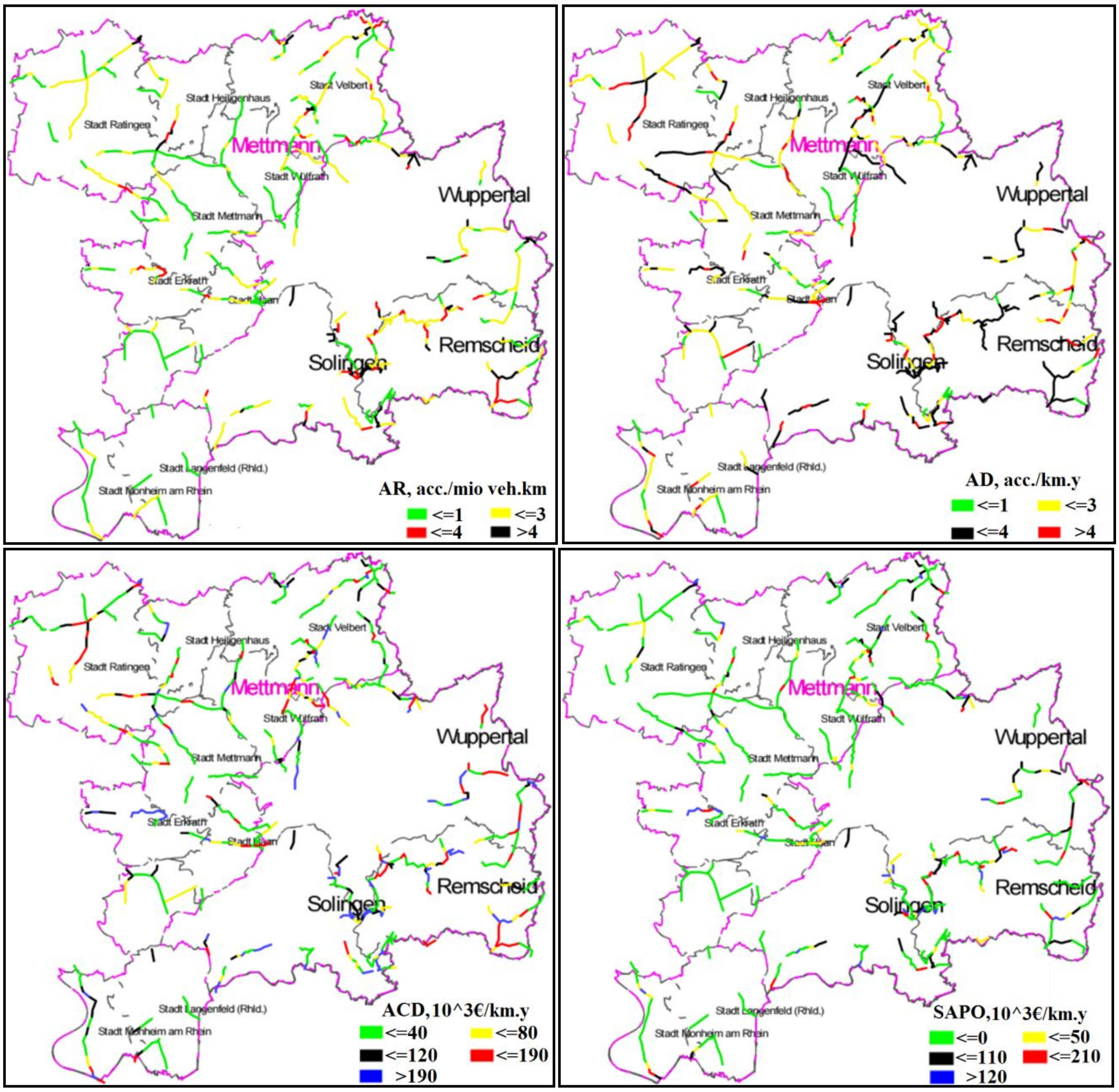


Figure 4.12: Accidents rate (AR), accidents density (AD), accidents cost density (ACD) and safety potential (SAPO) distribution maps.

If we take the same area but now map the accident density (upper right map) and accident cost density (lower left map), looking at different parts of the road network reveals a slightly different distribution. There is quite a wide range for each road section, from high density to low density. In the forth plot, we assigned the routes to five bands according to their safety potential ratings. The first band (low safety potential) includes high number of road sections (green sections).

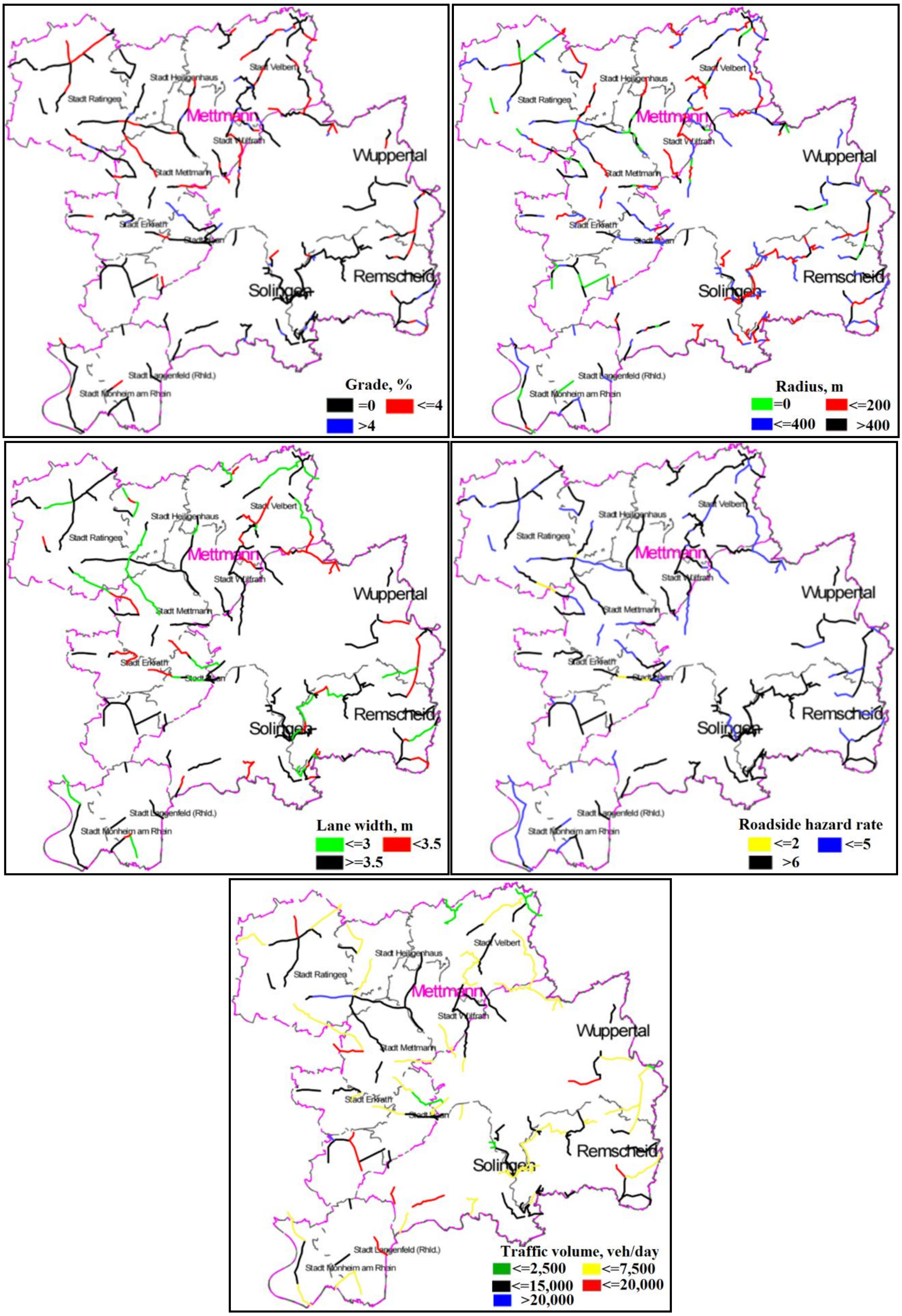


Figure 4.13: Grade, radius, lane width, roadside hazard rate and traffic volume distribution maps.

The highest safety potential sections occurred the most in Velbert, Solingen, Wuppertal and Remscheid cities. We can observe yet more information by looking at the maps in Figure 4.13. There is a high traffic volume (greater than 7500 veh/d), unsatisfactory roadside, flat terrain, and a variety of radii and lane width for the most segments.

4.7.2 Data clustering

Cluster analysis is the common term for a variety of numerical methods used to create objective and stable classifications. The primary objective is to find groups of similar entities in a sample of data. In short, cluster analysis groups together individuals with similar patterns of scores on variables. In the current analyses, the statistical software SPSS is adopted to perform the clustering analysis [134].

The cluster analyses were based on combinations of variables, including various geometric design characteristics: grade, radius, lane width, driveway density, roadside hazard rating, and traffic volume. Since not all the items were scored on the same scale, the standardized values (z-values) were used in the analyses.

To determine the number of clusters present in the data set, an initial hierarchical cluster analysis was carried out. Although there are no formal rules to determine the number of clusters, some heuristics have been suggested. By observing the coefficients which indicate the distance between each cluster, it should be possible to see a sudden jump in the distance between the coefficients. The stage before the sudden change indicates the optimal stopping point for merging clusters. The present analysis suggests that three clusters are present in the data. This is determined by referring to the accident cost rate (ACR) distribution.

Hierarchical clustering is useful to determine the number of clusters in the data. However, it cannot produce the most optimal cluster solution in terms of between-clusters heterogeneity. To do this, an iterative partitioning method (k-means) needs to be used. In short, based on a specified (k) number of cluster centers, a k-means cluster analysis allocates each case to the cluster that has the nearest centre point. When all subjects are sorted, the final cluster solution can be obtained [133].

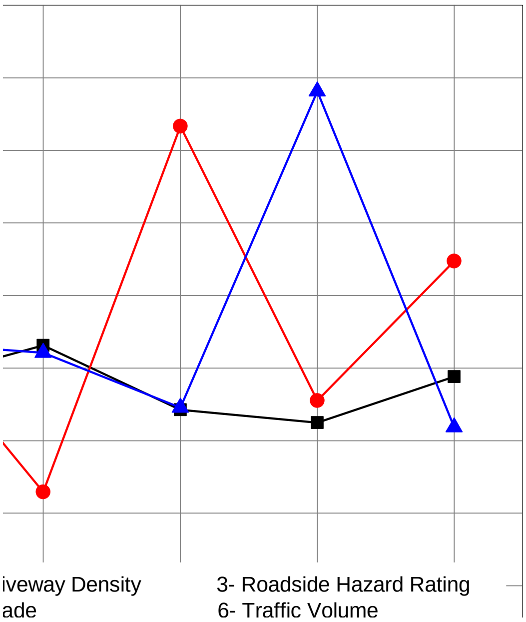


Figure 4.14: Plot showing the obtained three-cluster solution (z-scores).

The final cluster solution is presented in Figure 4.14. The typical cluster 3 member is characterized by high grade mean, i.e. the mean value is 1.9-fold higher than the grade mean value of the total obtained data. This is accompanied by a low score on traffic volume (the mean value is 0.44-fold lower than the mean traffic volume value of the total obtained data) and lane width (0.41-fold less).

The members of cluster 2 obtain relatively high scores on radius (the mean value is 1.67-fold higher than the total obtained data) and lane width (0.65-fold higher), and traffic volume (0.74–fold) and lane width (0.52-fold). This cluster is also characterized by a low roadside hazard rating score (0.64–fold less; i.e. more roadside safe). The first cluster is characterized by a low grade (0.38-fold less).

A closer look at the cluster structure (Figure 4.14) reveals that there are several systematic differences between the groups. First, the horizontal curves for members of clusters 1 and 3 are sharper than members of cluster 2. Secondly, the members of clusters 1 and 2 have less vertical gradients and traffic volume than members of cluster 3. Thirdly, the members of cluster 2 obtain higher scores on lane width, driveway density, radius, and traffic volume than members of cluster 3.

Referring to the distance value between final cluster centers in Table 4-10, the high distance between cluster 2 and cluster 3 shows that these clusters are divergent. By contrast, the low distances between clusters 1 and 2 and clusters 1 and 3 mean they are convergent.

Table 4-10: Distances between final cluster centers.

Cluster	**1**	**2**	**3**
1		2.434	2.366
2	2.434		3.384
3	2.366	3.384	

To investigate how members of the different clusters varied, the analyses of variance (ANOVA) were used. The mean differences between the clusters are in general largest on grade and smallest on driveway density (as shown in Table 4-11).

Table 4-11: ANOVA table - differences between clusters.

	Mean Square	**F**
Lane width	16.3	17.431
Driveway density	**5.8**	5.912
Roadside hazard rating	29.5	33.549
Radius	112.0	214.233
Grade	**155.6**	468.385
Traffic volume	25.2	28.195

4.7.3 Road geometrical design elements and accident characteristics relationships for the clusters

As shown in Figure 4.15, the analysis results for the relationships between road geometric design elements and accidents rate for the clusters generally are agreed with those represented in section 4.5. They also agree with engineering intuitions. However, the effect of road geometric design elements on accidents rate for the three clusters have better explanations than one group.

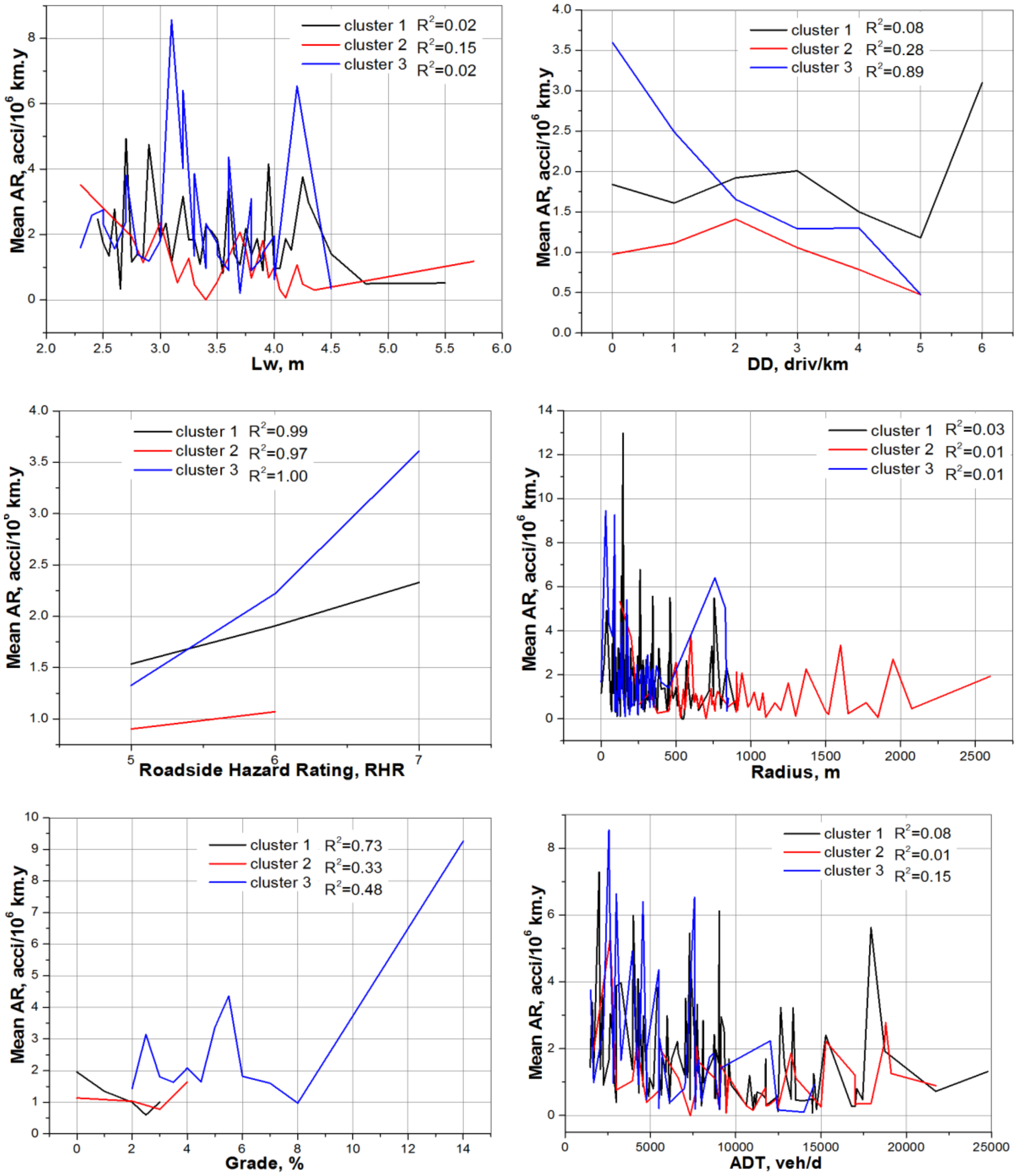


Figure 4.15: Lane width, driveway density, roadside hazard rating , radius, grade, and traffic volume relationships with the mean accidents rate for the clusters.

By comparing the r-squared value given in Table 4-12, we can note that the small variation (high dependency) in the accident rates occurrence is explained by geometric design elements by using clustering. In addition, we can see that the accident rates have high dependency with roadside hazard rating variable. This due to the low differences of road hazard rating between the members of the clusters (ANOVA =29.5) (as shown in Table 4-11) 3). A closer look at the cluster structure (Figure 4.14) reveals that the members of clusters 1 and 3 obtain relatively convergent scores on RHR (mean value is 0.11-fold and 0.16-fold respectively higher than the RHR mean value of the total obtained data), and they have higher RHR than members of cluster 3 (-0.85-fold), generally there are low differences in RHR among the clusters. Additionally the roadside hazard rating variable consist three values and by the clustering each cluster have two or three values. Therefore, the high r^2 for roadside hazard rating is due to only two or three points per cluster (as shown in Figure 4.15). This means that the statistical reliability of the correlation coefficient is not given.

However, the results of the cluster analysis also contain other useful information that can provide interesting insights into the various accident road element relationships, which are lost when reducing each cluster to a short one-sentence description.

Table 4-12: The R-squared between accident rate and geometric design elements.

Variables	**R^2 ungrouped**	**R^2 of clusters**		
		Cluster 1	**Cluster 2**	**Cluster 3**
Lane width	0.02	0.02	0.15	0.02
Driveway density	0.22	0.08	0.28	0.89
Roadside hazard rating	0.002	0.99	0.97	1.00
Radius	0.01	0.03	0.1	0.1
Grade	0.40	0.73	0.33	0.48
Traffic volume	0.07	0.08	0.01	0.15

4.8 Chapter summary

In this chapter, preliminary and regression analyses were conducted between accident rates and each geometric design characteristic. The purpose of these analyses was to investigate the trends of relationships between road parameters and accident rates. Regression analyses of accident rates versus lane width, driveway density, roadside hazard rating , radius, grade, and traffic volume, showed that the direction of its impact agrees with engineering intuition.

Another examination conducted during the preliminary analysis evaluated the relationship between accident rates and the average daily traffic volumes on the roads studied. This relationship was expected to be non-linear as some researchers have suggested.

As can be noticed in this chapter, the correlations are relatively low, because there is a relatively high dispersion of the data. This was expected, since accidents happen as a result of numerous and different factors, with each factor contributing differently to the occurrence of an accident. Moreover, these factors and their relative contribution typically change from one accident to another.

In Network Safety Management NSM, the key parameter for assessing the safety performance of road sections is the so-called safety potential. The aim of this analysis is to understand the dysfunctions of the road before implementing countermeasures. As a result of ranking sections by their potential savings in accident costs in the study area, the analysis revealed that the safety potential of the huge section is about 642 10^3 €/ (km.y). Based on the detected conspicuous accident patterns and its analysis, suitable countermeasure schould be derived. Head-on and run-off accidents were common on this section. The counter-measures that might reduce the potential for these accident types are: improving delineation; erecting crashworthy barrier systems on medians or roadside and/or guardrail barriers; applying the rumble strip along edge- or centerline; and geometric improvements.

The algorithm that combines a mapping technique (NSM) and statistical methods (cluster analysis) provided both statistical and geographical information on the accident events, in order to assess accident risk. The results showed that the distribution of the accident density and accident cost density were different, while the high accident rate was concentrated in Velbert, Wuppertal and Remscheid cities. By referring to the accident cost rates (ACR) distribution, the road sections were disaggregated into three clusters.

The results of the cluster analysis contain useful information that can provide interesting insights into various accident-road element relationships, which are lost when reducing each cluster to a short one-sentence description.

5 Evaluation of IHSDM

5.1 Introduction

The Interactive Highway Safety Design Model (IHSDM) is a suite of software developed by the Federal Highway Administration (FHWA) for monitoring and analyzing two-lane rural highways in the United States. As IHSDM is a fairly young program, a limited amount of research has been conducted to evaluate its practicability and reliability.

Koorey has applied the model and concluded that IHSDM is a promising tool for safety and operational assessment of highway alignments in New Zealand [135]. Already other countries (e.g. Canada, Spain) have also recognized the potential for customizing it for their own jurisdictions [136,137].

IHSDM consists of six models: a Policy Review Model (PRM), a Crash Prediction Model (CPM), a Design Consistency Model (DCM), a Traffic Analysis Model (TAM), an Intersection Review Model (IRM), and a Driver/Vehicle Model (DVM). Among the six models, the Intersection Review Model was not used because we evaluated only the segments between intersections.

5.2 Interactive highway safety design model overview

IHSDM is a suite of software analysis tools for evaluating the safety and operational effects of geometric design decisions on two-lane rural highways [115] carried out by the US Federal Highway Administration and developed since 1993.

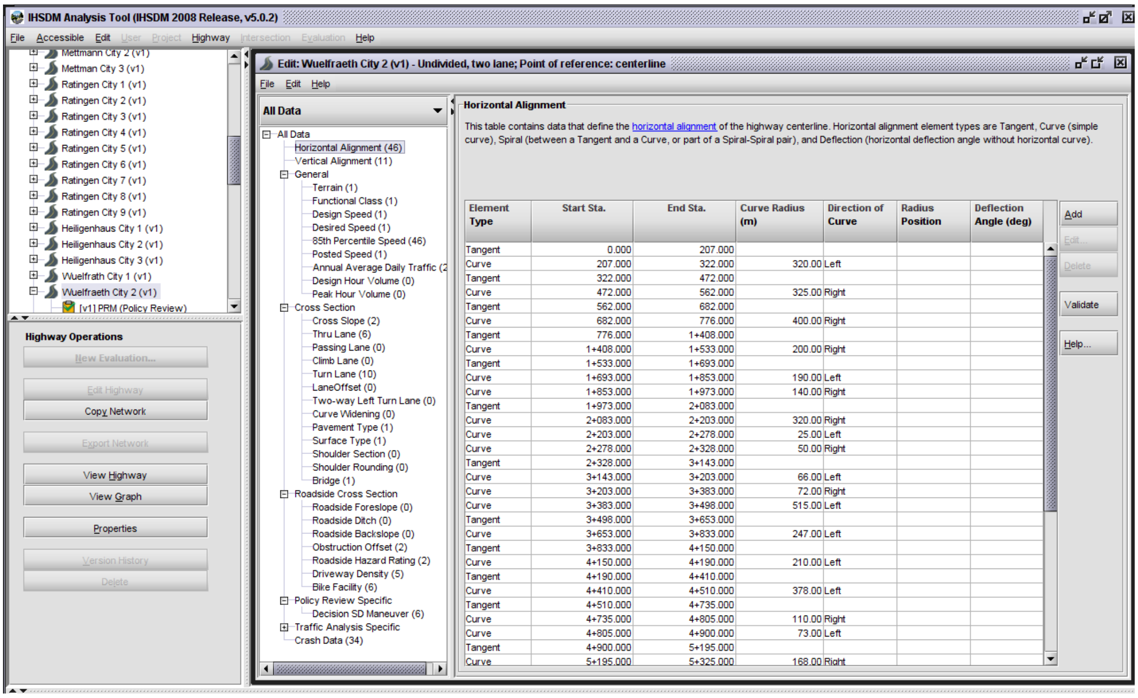
The IHSDM was released for the general public in September 2004 (v2.08). Updated versions were released in May 2007 (v3.00d) and March 2008 (v4.05). This study used the IHSDM 2008 version, which was the latest version available. The differences between these versions are largely cosmetic in nature, in terms of how the program presents the workflow of tasks. The underlying models for crash prediction, speed estimation, etc, have not been changed.

IHSDM is available for downloading from a public website (www.ihsdm.org); new users have to register their details to obtain access to the download webpage. A full version of IHSDM is typically 50MB in size to download, including the associated help documentation and support software (e.g. Java run-time engine). Minor updates may require a smaller patch file to download instead.

IHSDM's help documentation notes that IHSDM is targeted at the Microsoft Windows 95/98/NT/2000/ME/XP/Vista environment (although in theory, the Java-based software should be operable on other systems with suitable Java engines). As well as the appropriate windows operating system, a suitable HTML web browser with the Adobe Reader plug-in is also required for viewing output reports e.g. Firefox, Netscape Navigator or Microsoft Internet Explorer [138].

IHSDM is a decision-support tool. It checks existing or proposed two-lane rural highway designs against relevant design policy values, and provides estimates of a design's expected safety and operational performance. IHSDM results support decision-making in the highway design process. Intended users include highway project managers, designers, and traffic and safety reviewers in state and local highway agencies and engineering consulting firms [138].

IHSDM's goal is to provide transportation engineers with a tool that will help them design safe two-lane rural highways. IHSDM requires proper training and the understanding of highway geometric design and traffic safety issues related to two-lane rural highways. Also, IHSDM allows alignment data to be transferred directly from other software programs, such as GEOPAK and CAiCE, the engineering programs that are developed Bentley and Autodesk [139].



This table contains data that define the horizontal alignment of the highway centerline. Horizontal alignment element types are Tangent, Curve (simple curve), Spiral (between a Tangent and a Curve, or part of a Spiral-Spiral pair), and Deflection (horizontal deflection angle without horizontal curve).

Element Type	Start Sta.	End Sta.	Curve Radius (m)	Direction of Curve	Radius Position	Deflection Angle (deg)
Tangent	0.000	207.000				
Curve	207.000	322.000	320.00	Left		
Tangent	322.000	472.000				
Curve	472.000	562.000	325.00	Right		
Tangent	562.000	682.000				
Curve	682.000	776.000	400.00	Right		
Tangent	776.000	1+408.000				
Curve	1+408.000	1+533.000	200.00	Right		
Tangent	1+533.000	1+693.000				
Curve	1+693.000	1+853.000	190.00	Left		
Curve	1+853.000	1+973.000	140.00	Right		
Tangent	1+973.000	2+083.000				
Curve	2+083.000	2+203.000	320.00	Right		
Curve	2+203.000	2+278.000	25.00	Left		
Curve	2+278.000	2+328.000	50.00	Right		
Tangent	2+328.000	3+143.000				
Curve	3+143.000	3+203.000	66.00	Left		
Curve	3+203.000	3+383.000	72.00	Right		
Curve	3+383.000	3+498.000	515.00	Left		
Tangent	3+498.000	3+653.000				
Curve	3+653.000	3+833.000	247.00	Left		
Tangent	3+833.000	4+150.000				
Curve	4+150.000	4+190.000	210.00	Left		
Tangent	4+190.000	4+410.000				
Curve	4+410.000	4+510.000	378.00	Left		
Tangent	4+510.000	4+735.000				
Curve	4+735.000	4+805.000	110.00	Right		
Curve	4+805.000	4+900.000	73.00	Left		
Tangent	4+900.000	5+195.000				
Curve	5+195.000	5+325.000	168.00	Right		

Figure 5.1: IHSDM screenshot [115].

5.3 Entering data into IHSDM

IHSDM allows a number of different ways for road data to be created or directly imported into the program [140]:

- Data can be manually entered using IHSDM’s Highway Editor tool, although this can be very time consuming, given the amount of design detail that IHSDM may require.
- IHSDM "comma separated values" (CSV) files can be imported. These are text-based and contain formatted geometric and non-geometric data related to one or more highways. Although these can be created manually, they are typically produced by another IHSDM user exporting a CSV file from another road project.
- Industry standard LandXML files can be imported. Again, these can be created manually, but most road design software packages, such as Geopak or MX-Road, can produce LandXML files directly from their data.

Typically, the data required by IHSDM comprises geometric elements (such as horizontal curves and tangents, vertical curves and grades, and cross-section features), together with general road environment data (such as design speeds, terrain, and traffic volumes). For proposed alignments, obtaining this data is usually relatively straightforward, as most of the necessary information will already be determined in a road design program.

5.4 IHSDM analysis models

IHSDM consists of five analysis models, packaged together as a single application with associated support tools. The subsections below discuss each model.

5.4.1 Policy review model (PRM)

This model is intended for use in all stages of highway planning and design, including design review, for both new and reconstruction projects. Design elements that are not in compliance with a policy are identified, and an explanation of the policy violated is provided. In response to this information, the user may correct any deficiencies, analyse the design further using other IHSDM models, and/or prepare a request for a design exception. A summary of the policy review is provided, including a listing of all design elements that do not comply with policy [141].

The categories of design elements to be verified include: cross-sections, horizontal alignment, vertical alignment, and sight distance. The cross-section category checks the traveledwidth of the traveled way and its cross slope, auxiliary lane width and its cross slope, shoulder width and its cross slope, cross slope rollover on curves, and bridge width. The horizontal alignment category evaluates radius of curvature, superelevation, compound curve ratio, and length of horizontal curve. The vertical alignment category verifies tangent grade length and vertical curve length. The sight distance category checks stopping, passing, and decision sight distances. Additional checks are done for clear zone, roadside slope, normal ditch design, and superelevation transition.

The policy review model (PRM) is a digitized policy review that checks the 1990, 1994, 2001, and 2004 versions of AASHTO’s A Policy on Geometric Design of Highway and Streets.

IHSDM's System Administration Tool (SAT) allows users to create or edit policy files to use with the program. The interface allows various policy files to be present in the system, with the user specifying which one to use for each analysis. The SAT allows users to either create a completely new policy file (requiring users to enter in values for each data item) or to "clone" a copy of an existing policy file and then modify it to suit. Of note is that there appears to be no obvious way to remove a policy file from the SAT list, or to import a policy file developed elsewhere.

However, the process of editing and then closing any policy file forces IHSDM to recompile all policy files that it finds in the "policy" subdirectory [142]. The model also allows users to modify some of the policy tables to reflect unique policies that differ from the AASHTO policies.

5.4.2 Crash prediction model (CPM)

The crash prediction model (CPM) estimates the number and rate of crashes by evaluating the geometric design and traffic flow characteristics of two-lane rural highways. The crash prediction algorithm consists of three components: base models, a calibration factor, and accident modification factors (AMFs).

The general formula to predict the number of crashes for highway segments is shown below [118,143], and its procedure is described in Figure 5.2.

$$\mathrm{N_{rs}} = \mathrm{N_{br}} \,.\, \mathrm{C_r} \,.\, \mathrm{AMF_1}.\mathrm{AMF_2}.\mathrm{AMF_3}.\mathrm{AMF_4}.\mathrm{AMF_5}.\mathrm{AMF_6}.\mathrm{AMF_7}.\mathrm{AMF_8}.\mathrm{AMF_9} \qquad (5\text{-}1)$$

where N_{rs} is the predicted number of total highway segment crashes per year, N_{br} is the predicted number of total highway segment crashes per year for nominal or base conditions, C_r is the calibration factor for highway segments, AMF_1 ,..., AMF_9 are the accident modification factors for highway segments, ADT_n is the average daily traffic volume for a specified year n (veh/day), and L is the length of the highway segment (km).

The base models provide an estimate of the safety performance of a roadway for a set of assumed nominal or base conditions. The equation of the base models for roadway segment is [118,143,144]:

$$\mathrm{N_{br}} = \mathrm{ADT_n} \times \mathrm{L} \times 365 \times 10^{-6} \times e^{-0.4865} \qquad (5\text{-}2)$$

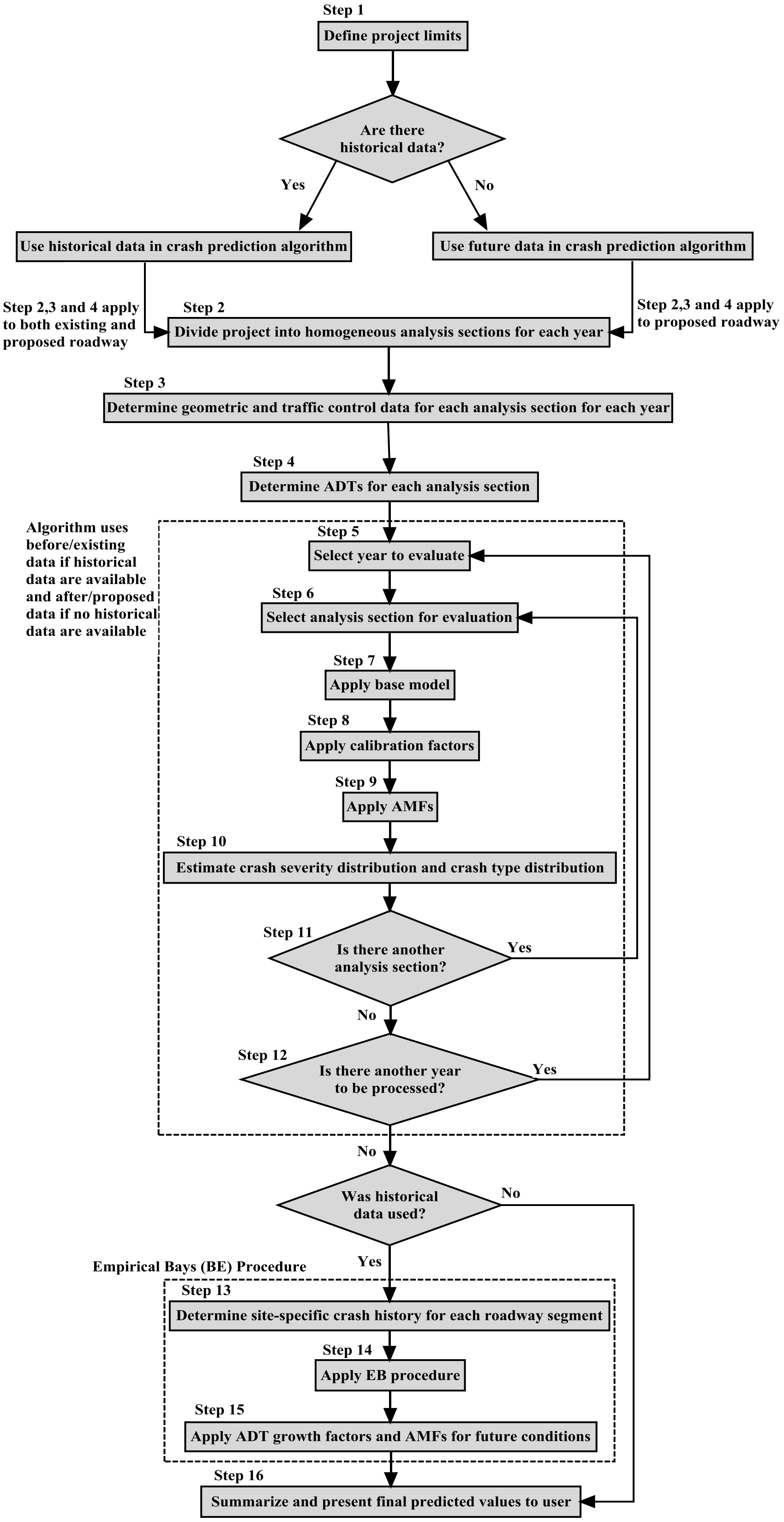


Figure 5.2: Crash prediction algorithm flowchart [118].

The state variable in the base model is set equal to zero, representing Minnesota conditions. It should be noted that the calibration procedure can be used to adapt the base models to the safety conditions of any other state.

There are several factors that lead to safety differences between highway agencies in different geographical areas that are not directly accounted for by the accident prediction algorithm. These include:

- differences in climate (i.e. exposure to wet pavement and snow-and-ice-covered pavement conditions);
- differences in animal populations that lead to higher frequencies of collision with animals in some states than in others;
- differences in driver populations and trip purposes (i.e. commuter vs. commercial vs. recreational travel);
- accident reporting thresholds established by state law (i.e. a minimum property damage threshold that requires reporting of an accident);
- and accident investigation practices (i.e. some police agencies are much more diligent about investigating and reporting property-damage-only collisions than others).

The calibration procedure is intended to account for these differences and provide accident predictions that are comparable to the estimates that a highway agency would obtain from its own accident records system. The procedures for a particular highway agency to estimate calibration factor Cr for roadway sections are described in Appendix III.

It is generally expected that the calibration factor C_r would be determined by highway agencies based on statewide data. In larger and more diverse states, a highway agency might choose to develop separate calibration factors for individual highway districts or climate regions. It is also possible for users to provide a local calibration factor for smaller areas with distinct driver populations or climate conditions.

States differ markedly both in terrain and in the history of the development of their highway system, resulting in state-to-state differences in roadway alignment, cross-section, and intersection design. However, differences of this type are accounted for by the AMFs in the accident prediction algorithm.

The AMFs adjust the base model predictions to account for the effects on safety for roadway segments of various site features. These features include lane width, shoulder width, shoulder type, horizontal curves, grades, driveway density, two-way left-turn lanes, passing lanes, and roadside hazards. The procedures for determining the values of the AMFs for highway segments (AMF_1 through AMF_9) are described in Appendix IV.

The CPM also includes an Empirical Bayes (EB) procedure that can be applied to weight the safety predictions provided by the algorithm with actual site-specific crash history data.

For each highway segment, the EB procedure is applied by computing the expected crash frequency as a weighted average of the predicted and observed crash frequencies, as:

$$E_p = w \times N_{rs} + (1 - w)O \qquad (5\text{-}3)$$

where E_p is the expected crash frequency based on a weighted average of N_{rs} and O, w is the weight to be placed on the crash frequency predicted by the crash prediction algorithm, and O is the number of crashes observed during a specified period of time.

The weight placed on the predicted crash frequency is determined by:

$$w = 1/[1 + 0.345(N_{rs}/L)] \qquad (5\text{-}4)$$

This step is applied both to total crash frequencies and to crash frequencies by crash severity level (i.e. fatal and injury crashes, and property-damage-only crashes). Since these computations are independent, the expected crash frequencies by severity level may not equal the expected total crash frequency. A correction is made as follows, so that the expected crash frequencies for the individual severity levels are equal to the expected total crash frequency:

$$E_{fi/corr} = \frac{E_{tot} \times E_{fi}}{E_{fi} + E_{pdo}} \qquad (5\text{-}5)$$

$$E_{pdo/corr} = \frac{E_{tot} \times E_{pdo}}{E_{fi} + E_{pdo}} \qquad (5\text{-}6)$$

where $E_{fi/corr}$ is the expected crash frequency for fatal and injury crashes (corrected), $E_{pdo/corr}$ is the expected crash frequency for property-damage-only crashes (corrected), E_{tot} is the expected crash frequency for total crashes as estimated with equation 5-3, E_{fi} is the expected crash frequency for fatal and injury crashes as estimated with equation 5-3, and and E_{pdo} is the expected crash frequency for property-damage-only crashes as estimated with equation 5-3.

The ADT growth factors and/or AMFs for geometric changes are then applied, in order to convert the expected crash frequency for the before period to an expected crash frequency for the proposed project during the specified future time period.

At the conclusion of the last step, E_p represents the expected crash frequency for a given highway segment during the before period. To obtain an estimate of expected accident frequency in a future period (the analysis or after period), the estimate must be corrected for:

- any difference in the duration of the before and after periods;
- any growth or decline in ADT between the before and after periods;
- and any changes in geometric design or traffic control features between the before and after periods that affect the values of the AMFs for the highway segment.

The expected crash frequency for a highway segment in the after period can be estimated as:

$$E_f = E_p\left(N_{rs\,f}/N_{rs\,p}\right)\left(AMF_{1f}/AMF_{1p}\right)\left(AMF_{2f}/AMF_{2p}\right)\ldots\left(AMF_{nf}/AMF_{np}\right) \qquad (5\text{-}7)$$

where E_f is the expected crash frequency during the future time period for which crashes are being forecast for the analysis segment in question, E_p is the expected crash frequency for the past time period for which crash history data were available, and $N_{rs\,f}$ is the number of crashes forecast by the base model using the future ADT data, the specified nominal values for geometric parameters, and (in the case of an analysis segment) the actual length of the analysis segment. $N_{rs\,p}$ is the number of crashes forecast by the base model using the past ADT data, the specified nominal values for geometric parameters, and (in the case of an analysis segment) the actual length of the analysis segment. AMF_{nf} is the value of the nth AMF for the geometric conditions for the future (i.e. the proposed analysis or after period) design, and finally AMF_{np} is value of the nth AMF for the geometric conditions for the past (i.e. the existing or before period) design.

Equation 5-7 applies to the total crash frequency. The expected future crash frequencies by severity level are determined by multiplying the expected accident frequency from the before period for each severity level by the ratio

$$E_{f(total)}/E_{p(total)} \text{ or } E_{f(severity\_level\_n)} = \frac{E_{p(severity\_level\_n)} \times E_{f(total)}}{E_{p(total)}} \qquad (5\text{-}8)$$

Crash prediction models are based on a negative binomial regression analysis that ensures sensitivity to site-specific geometric design and traffic control features. The CPM is more useful in identifying high crash locations than estimating specific crash frequency or rates. The ability of the CPM to predict crash occurrences increases if both historic crash data of either a similar site or the target road itself, and correct geometric design data of the highway section under study are available, as long as geometric conditions remain the same in the future [145].

5.4.3 Design consistency model (DCM)

Design consistency refers to a design's conformance with drivers' expectations. This is one important goal of design, and helps diagnose safety concerns at horizontal curves. Crashes on two-lane rural highways are highly represented at horizontal curves, and speed inconsistencies are a common contributing factor to crashes on curves.

The design consistency model (DCM) provides evaluation of potential speed inconsistencies. The model uses a speed-profile model that estimates 85th percentile vehicle speeds at each point along a roadway. The speed-profile model combines estimated 85th percentile speeds on curves (horizontal, vertical, and horizontal–vertical combinations), desired speeds on long tangents, acceleration and deceleration rates exiting and entering curves, and an algorithm for estimating speeds on vertical grades [1,146,147]

The model contains two safety criteria:

- Achieving design consistency (*safety criterion I*) is of special interest in modern highway geometric design. This means the design speed V_d should remain constant on longer roadway sections and should also be coordinated with the actual driving behavior expressed by the 85th percentile speed V_{85} (see Table 5-1).

- The 85th percentile speed should also be consistent along roadway sections. This is guaranteed by achieving operating speed consistency (*safety criterion II*), between two successive design elements. Tangents exist that are long enough to accelerate up to the top 85th percentile speed V_{85i} or to decelerate down to the 85th percentile speed V_{85i+1} on the succeeding curved section. Those long tangents are called independent tangents and must be regarded in the curve-tangent-curve design process as independent design elements. Short tangents, where critical acceleration and deceleration maneuvers are not possible, are called nonindependent tangents and can be ignored in the speed related design process (according to the limiting ranges in Tables 1 and 2 in Appendix V).

Table 5-1: Ranges for the safety criteria I and II [1].

Safety criterion	**Design levels**		
	GOOD Permissible differences	**FAIR** Tolerated differences	**POOR** Non-permissible differences
I$^{1)}$	$\lvert V_{85i} - V_d \rvert \leq 10$ km/h	10 km/h$<$ $\lvert V_{85i} - V_d \rvert$ ≤ 20 km/h	20 km/h$<$ $\lvert V_{85i} - V_d \rvert$
II$^{2)}$	$\lvert V_{85i} - V_{85i+1} \rvert \leq 10$ km/h	10 km/h$<$ $\lvert V_{85i} - V_{85i+1} \rvert$ ≤ 20 km/h	20 km/h $<$ $\lvert V_{85i} - V_{85i+1} \rvert$

$^{1)}$ Related to the individual design element “i” (independent tangent or curve) in the course of the observed roadway section.
$^{2)}$ Related to two successive design elements “i” and “i+1” (independent tangent-to-curve or curve-to-curve).

V_d = design speed (km/h).
V_{85i} = expected 85th percentile speed of design element “i” (km/h).
V_{85i+1} = expected 85th percentile speed of design element “i+1” (km/h).

The 85th percentile speed can be determined along an investigated roadway section for each individual curve in relation to the curvature change rate of the single curve with transition curves CCRs according to equation 5-9 [146]. For independent tangents, the 85th percentile speed is related to CCRs=0 gon/km.

$$V_{85} = \frac{10^6}{8270 + 8.01 \times \text{CCRs}} \qquad (5\text{-}9)$$

The formula for determining CCRs is

$$CCRs = \left(\frac{L_{c11}}{2R} + \frac{L_{cr}}{R} + \frac{L_{c12}}{2R}\right) \times \frac{63{,}700}{L} \qquad (5\text{-}10)$$

where L= L_{cr} +L_{c11}+Lc_{12} is the length of the curve (in km), L_{cr} is the length of a circular curve (in m), L_{c11} and L_{c12} are the lengths of clothoids (in m), and R is the radius of a circular curve (in m).

5.4.4 Traffic analysis model (TAM)

The traffic analysis model (TAM) can be used to evaluate the operational effects of existing and projected future traffic on a highway section, and the effects of alternative road improvements, such as realignment, cross-sectional improvements, and the addition of passing lanes or climbing lanes.

The core of the TAM is the TWOPAS (TWO-lane PASsing) rural traffic simulation model. TWOPAS is a microscopic simulation model of traffic on two-lane highways that takes realistic account of geometric, traffic control, driver behavior, and vehicle characteristics. Microscopic models can be very accurate and realistic because they trace through time the movements of individual vehicles and the decisions of individual drivers. Providing this realism requires extensive use of logic and computations. Most aspects of the model have been validated against traffic-operational field data. Spot speed and platooning data as well as overall travel time, speed, delays, and percentage time spent following are accumulated and reported [115,148,149].

TWOPAS Simulation Procedures [150]**:**

The TWOPAS model simulates traffic operations on two lane highways by updating the position, speed, and acceleration of each individual vehicle along the highway at one-second intervals as it advances along the road. The model takes into account *i)* the characteristics of the vehicle and its driver, *ii)* the geometrics of the roadway, and *iii)* the oncoming and same-direction vehicles that are in sight at any given time. The following features are found in the TWOPAS simulation model [151]:

- three general vehicle classifications: passenger cars, recreational vehicles, and trucks;

- roadway geometrics specified by the user, which include: horizontal curves, grades, vertical curves, sight distance, passing lanes, climbing lanes, and short four-lane sections;
- traffic controls specified by the user, of particular importance being passing and no-passing zones;
- traffic streams at each end of the simulated roadway generated in response to user-specified flow rate, traffic mix, and percent of platooned traffic;
- variations in driver behavior based on empirical data;
- driver speed in unimpeded traffic based on user-specified distribution of driver desired speeds;
- driver speed in impeded traffic based on a car-following model that simulates driver preferences for following distances (headways). This is based on three concepts: *i)* relative speeds of leader and follower, *ii)* desired speeds of drivers, and *iii)* driver's desire to pass the leader;
- driver decisions concerning initiating passing maneuvers, continuing or aborting passing maneuvers, and returning to normal lane, based on empirical data;
- driver decision concerning behavior in passing, climbing, or four-lane sections, including lane choice at the beginning of the added lane, lane changing or passing within added lanes and at lane drops, based on empirical data;
- and processing and updating of vehicle speeds, accelerations, and positions at intervals of 1 second of simulated time.

5.4.5 Driver/vehicle model (DVM)

The driver/vehicle module (DVM) is a computational model of driver behavior that simulates the driver's perceptual, cognitive, and control processes to generate steering, braking, and acceleration inputs to the vehicle. The objective of the DVM is to permit the user to evaluate how a driver would operate a vehicle (e.g. passenger, car or truck) through a geometric design, and to identify weather conditions exist that could result in the loss of vehicle control (e.g. skidding or rollover). The DVM represents a combination of two interacting models: the driver performance model (DPM) and the vehicle dynamics model (VDM) [115,152].

The DVM consists of five major computational functions: 1) perception, 2) speed decision, 3) path decision, 4) speed control, and 5) path control. Specific driver-perceptual and other processes are treated as relatively constant in DVM, although details of generating steering, braking, and acceleration processes can differ markedly with the vehicle driven, e.g. a passenger vehicle vs. an 18-wheel tractor-trailer truck. DVM is similar to other complex models of human behavior in that it contains many parameters that can only be estimated through empirical research. In order to acquire the data necessary for model development and validation, a series of road experiments were conducted. A key goal during DVM development was to simulate the complex interactions between roadway geometry, vehicle, and driver interactions that are not represented in the other IHSDM modules. DVM was developed to provide highway designers with a means for:

- readily evaluating the safety impacts of driver/roadway geometry interaction;
- and enhancing design for highway safety.

The DVM produces the following measures of effectiveness and, where appropriate, threshold or reference values for comparison purposes [115,152]:

- lateral acceleration;
- friction demand;
- rollover index in comparison with the rollover threshold;
- estimated vehicle speed;
- vehicle path (lateral offset) relative to the lane lines;
- lateral skid index in comparison to lateral skid threshold values;
- and longitudinal skid index in comparison to longitudinal skid threshold values.

5.5 Application of IHSDM

The study sections selected for analysis were all two-lane rural highways, which were the target study type of roads for IHSDM. There were 470 segments of 157 different state routes in Landkreis Mettmann (Wülfrath, Erkrath, Hann, Heiligenhaus, Hilden, Langenfeld, Mettmann, Monheim, Ratingen and Velbert cities) and Remscheid-Solingen-Wuppertal Kreisfreie Städte that were selected for analysis and divided to 63 highways depends on traffic volume (Average Daily Traffic, veh/h) as listed in the following:

1) L422-14
2) B 224-7 + L74-7 + L74-8 + L74-9 + L74-10 + L74-11
3) L422-11 + L426-1 + L426-2
4) L355-2
5) L357-1 + L357-2
6) L357-3 + L357-4 + L403-17
7) L357-9 + L357-10 + L357-11 + L357-12 + L357-13
8) L423-1 + L423-2 + L423-3
9) B228-8
10) L288-38
11) L156-3
12) L156-6 + L156-7
13) B227-4,2
14) B228-4
15) L282-1 + L282-2
16) L403-11 + L403-12 + L403-13
17) L43-8 + L43-9 + L108-6
18) L403-1 + L403-2
19) L402-2

20) L403-8,2

21) B7-35

22) B7-39 + B7-40

23) L403-19

24) L293-7 + L293-8 + L293-10

25) L239-1 + L239-2

26) L156-1

27) L422-7 + L422-8

28) L422-10

29) L139-2 + L139-3

30) L139-5 + L139-6 + L139-7

31) B227-1 + B227-2 + B227-3

32) L441-1

33) L239-7

34) L433-7 + L433-8 + L433-9 + L433-10 + L433-11

35) L107-1 + L107-2 + L107-3

36) L427-19 + L427-20 + L427-20.1 + L427-21

37) L107-5 + L107-6 + L107-7 + L107-8 + L427-23

38) L427-22 + L107-9 + L107-10

39) B227-17 + B227-18

40) L427-26 + L427-27 + L427-28 + L427-29

41) L924-4 + L924-5 + L924-6

42) L107-15 + L107-16 + L439-7

43) L74-1 + L427-5 + L427-6 + L427-7

44) L427-8

45) B51-76 + L411-1 + L411-2 + L411-3 + L414-9

46) L81-7

47) L527-3 + B51-82 + L419-1 + L419-2
48) B51N-180
49) B229-6 + B229-8
50) L427-1
51) L407-1
52) L157-8 + L 157-9
53) L407-2 + L407-3
54) L288-28
55) L288-32
56) B229-15 + B229-16
57) L216-1 + L216-2
58) L415-5 + L415-6
59) L81-1 + L157-14
60) L417-1 + L417-2
61) B237-1 + B237-2 + B51-72
62) B51-73 + L412-1 + L412-2
63) B229-24

The results of analysis for IHSDM will be discussed in the following subsections with a focus on one case study as an example.

Highway ***(B224-7 + L74-7 + L74-8 + L74-9 + L74-10 + L74-11)***

This highway is located in Wülfrath city in Landkreis Mettmann (North Rhine Westphalia) with total length 8.235 km. The traffic volume (ADT) at this highway was about 8,844 veh/h for Bundesstrasse (B) and 14,739 veh/h for Landesstrassen (L) in 2000. Figure 5.3 shows the overall highway plan. The highway is indicated by the dotted black line.

5.5.1 Policy review model evaluation results

The goal of the policy review model (PRM) is to "check a design relative to the range of values for critical dimensions recommended in AASHTO design policy".

In its output report (see Appendix VI), the PRM shows comments for the traveled-way width and widening, bridge width, radius of curve, tangent grade, stopping sight distance, passing sight distance, and decision sight distance. These are intended to provide guidance to the designer by referencing a recommended range of values for critical dimensions, which are described in Table 5-2 as an example. The PRM also computes the stopping sight distance (SSD) from the horizontal and vertical alignment and cross-section data in the IHSDM highway data file for the highway being evaluated. SSD is the distance that a driver must be able to see ahead along the roadway in order to identify hazards in the roadway and bring his or her vehicle safety to a stop where necessary [153].

Table 5-2: Traveled way width and widening - sample (3 sections).

Stations		**Traveled Way (width+widening), m**		**Comment**	**Attributes**
Start	**End**	**Road**	**Policy**		
0.000	207.000	8.50 + 0.00	7.20 + 0.00	Road value is within controlling criteria	design speed=80 (km/h); class=arterial; terrain=level; ADT=8,844 (v/day)
1+693.000	1+853.000	7.40 + 0.00	7.20 + 1.30	Road value varies from controlling criteria	design speed=80 (km/h); class=arterial; terrain=level; ADT=14,739 (v/day); radius=190.00 (m); Policy TWW=7.20 m
1+853.000	1+973.000	7.40 + 0.00	7.20 +...	No policy values in AASHTO 2004 Metric: minimum curve widening	design speed=80 (km/h); class=arterial; terrain=level; ADT=14,739 (v/day); radius=140.00 (m); Policy TWW=7.20 m

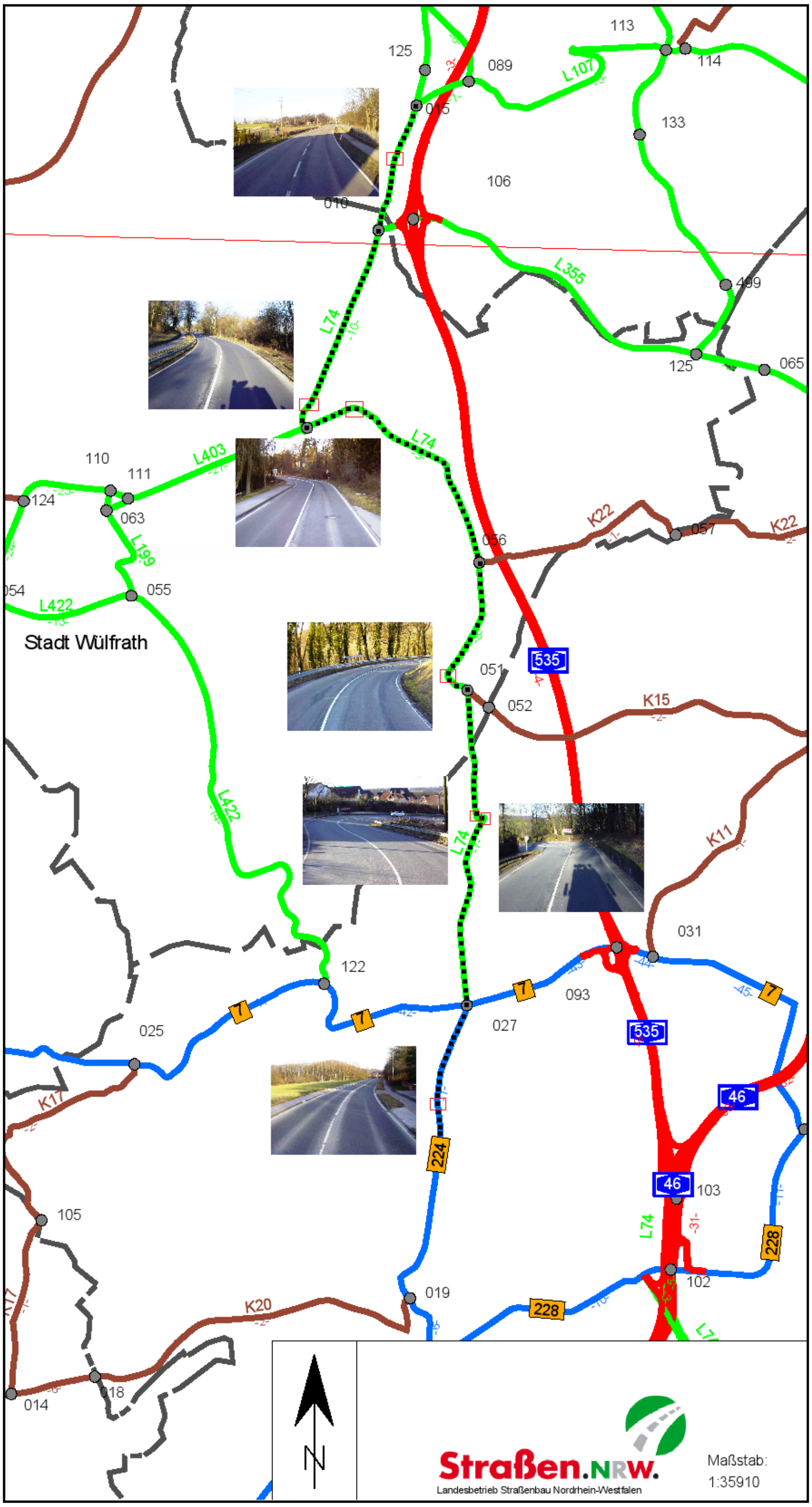


Figure 5.3: Plan of highway (B224-7 + L74-7 + L74-8 + L74-9 + L74-10 + L74-11) [113].

The available SSD is a function of the highway geometry and roadside features; it is therefore not constant along an alignment or analysis section as shown in Figure 5.4. The available SSDs vary along the highway sections and 45% of the sections were under the minimum required SSD (130 m). By using Statistical Package for the Social Sciences (SPSS® 16.0, 2007), we found the correlation between SSD and curve radius is very low (0.01), also between SSD and AR is low (0.24).

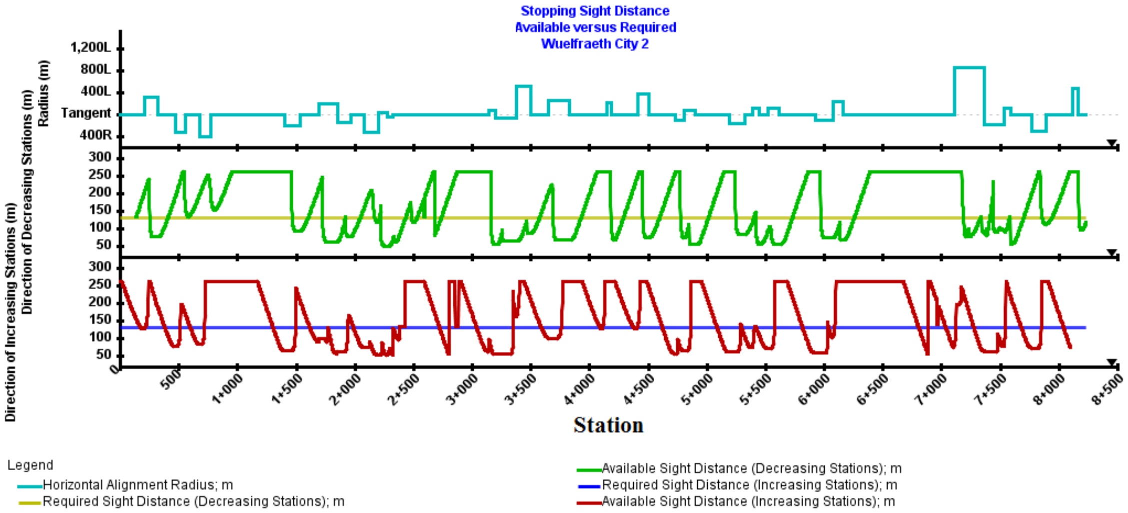


Figure 5.4: Graphical output for stopping sight distance check.

The comparative study of the correlation between the minimum required SSD design values for Germany and USA is presented in Table 5-3.

Table 5-3: Minimum required SSD on level terrain for Germany and USA[1].

	Operating speed, km/h										
	30	40	50	60	70	80	90	100	110	120	130
	SSD, m										
Germany	-	-	-	65	85	110	140	170	210	255	305
USA	30	44	63	85	111	130	169	205	246	286	-

According to AASHTO [154], most roads are considered to qualify as two-lane rural highways on which faster moving vehicles frequently overtake slower ones, the passing of which must be accomplished on lanes regularly used by opposing traffic. If passing is to be accomplished safely, the driver should be able to see a sufficient distance ahead, clear of traffic, in order to complete the passing maneuver without cutting off the passed vehicle in advance of meeting an opposing vehicle appearing during the maneuver. The design values for passing sight distance (PSD), as used in Germany and the USA, are presented in Table 5-4.

Table 5-4: PSD criteria used in geometric design in Germany and USA[1].

	Operating speed, km/h									
	30	40	50	60	70	80	90	100	110	120
Germany	-	-	-	475	500	525	575	625	-	-
USA	217	285	345	407	482	541	605	670	728	792

The available PSD is a function of the highway geometry and roadside features and, therefore, is not constant along an alignment or analysis section. Available PSDs are generally under the "minimum required PSD" line, as shown in Figure 5.5.

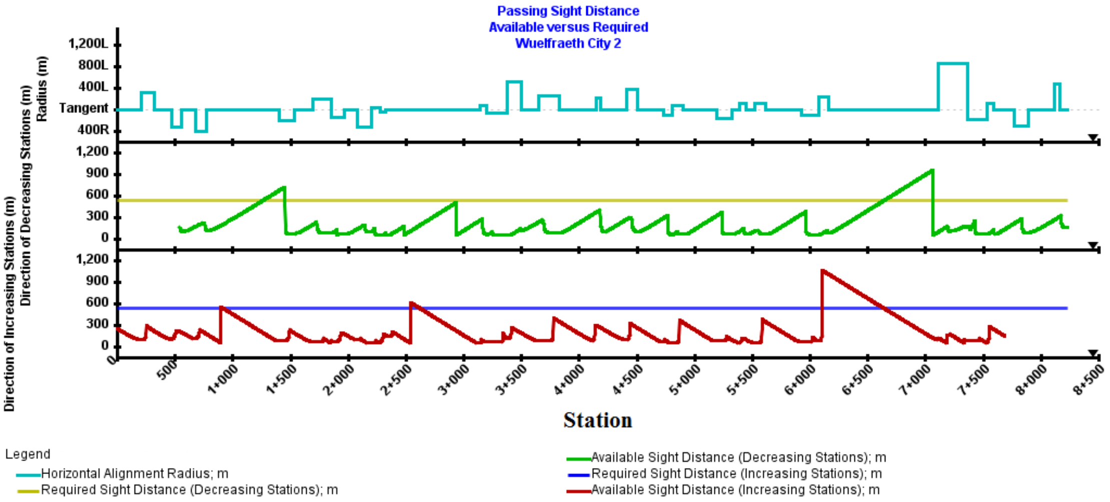


Figure 5.5: Graphical output for passing sight distance check.

5.5.2 Crash prediction model evaluation results

The previously imported road alignment data was used in IHSDM's CPM to estimate crash numbers, and the crash history data was also exported from the database to an IHSDM file and then imported into IHSDM for processing.

The IHSDM CPM analysis was undertaken both with and without the local crash history being incorporated (using Empirical Bayes). IHSDM checks for this by ensuring that the crash history analysis period and the analysis period for crash prediction do not overlap.

Table 5-5 summarizes the resulting crash frequencies and rates; the expected values are taken from "Table 5" of IHSDM's outputs (see Appendix VI).

Table 5-5: Observed and expected crash rates and frequencies.

Description	**Observation 2000-2005**	**Expected (crash history)**	**Expected (no crash history)**
Total Crashes	109	122	269
Fatal and Injury Crashes	29 (27%)	45 (37%)	86 (32%)
Property-damage-only Crashes	80 (73%)	77 (63%)	183 (68%)
Average Traffic Volume (vehicles/day)	14,739	14,057	14,057
Crash Rate per kilometers per year	2.2	2.5	5.5
Total travel (million vehicle-kilometers)	265.8	253.5	253.5
Crash Rate per million vehicle-kilometers	0.4	0.5	1.1

The crash model predictions give a particularly good estimate of the actual observed numbers, which in the addition of crash history data pushes the prediction estimate much closer to the observed total number (approximately 10% higher). While without crash history data, the model overestimates the actual number of crashes by about 60%.

The CPM provides assessment of the road elements causing the crashes. In Figure 5.6 it can be seen that many of the expected crash rates (with crash history) occurred in the vicinity of the observed crashes (although not always matched to the same element), with also a high correlation between them (0.93). The expected crash rates without crash history data is, however, higher than the observed crash rates.

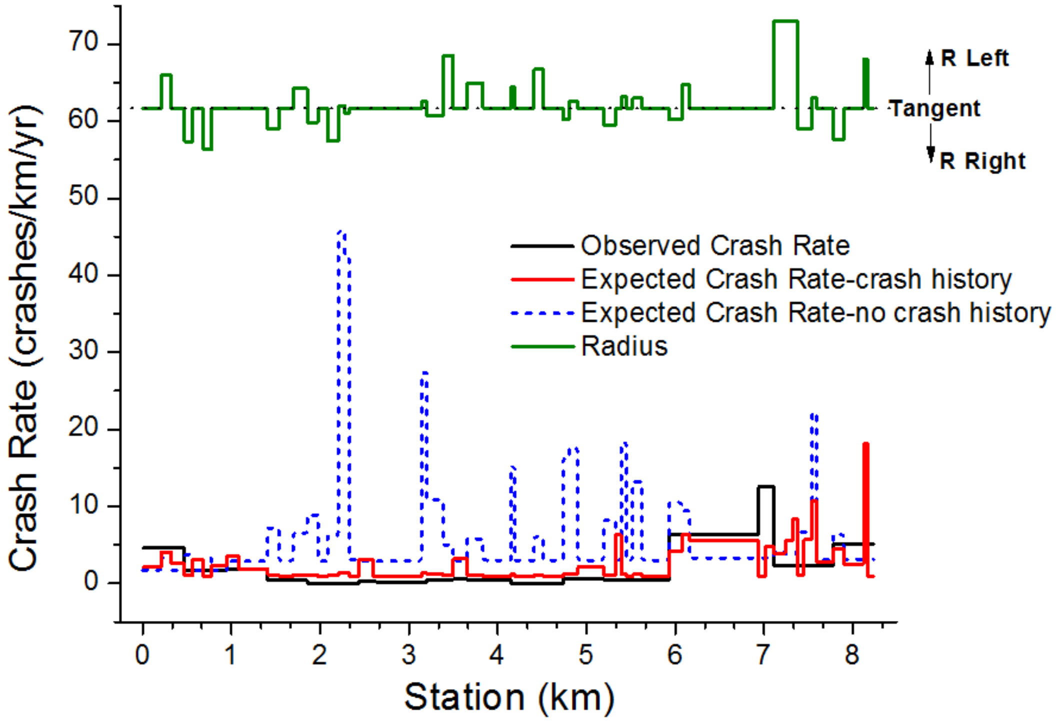


Figure 5.6: The Relationship of observed and the expected crashes rate.

5.5.3 Design consistency model evaluation results

One factor that does not appear to be well recognized in the existing CPM is the effect of speed consistency. All the factors used in the base model and AMFs are measures ascertained for each road element down the highway, but there appears to be no allowance for interaction between adjacent elements. However the DCM can be used to identify where there are any speed inconsistencies between adjacent sections.

Figure 5.7 shows the geometric and speed details for the highway as processed by IHSDM's DCM. Note that traveling from left to right on the plot is in the northbound direction (the data for the opposite traveling direction is very similar).

It can be seen (Figure 5.7) that the design consistency (criteria I: *"the absolute difference between the 85th-percentile speed and the selected design speed"*) is good, as evidenced by the green line (and no yellow or red ones). However, the operating speed consistency (criteria II: *"the absolute difference between the 85th-percentile speeds between successive design elements"*) is poor in three transitions, as evidenced by the red flags (which are represented in Figure 5.8). This indicates a well-balanced design or good curvilinear alignment. However, with respect to poor design practice according to safety criteria II, a change of more than 20 km/h in operating speeds would certainly be an unbalanced design, or create a critical alignment.

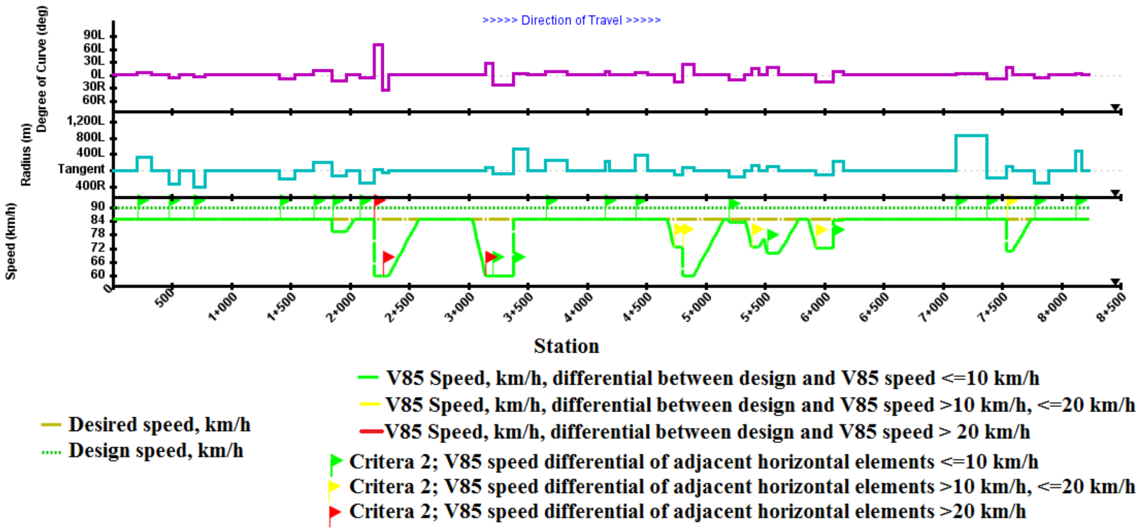


Figure 5.7: DCM graphical output for increasing direction of travel.

In order to achieve operating speed consistency between two circular curves in the same or in opposite directions, the radii of these curves should be in a well-balanced relationship (known as relation design). The same is true for the transition of independent tangent to curve [146]. The relation design should ensure that motorists adapt their speed to the present geometry of the road, and that only low speed differences with low deceleration rates should exist in front of or within curves themselves.

According to the relation design background (Figure 4, p.14) from the “German Guidelines Richtlinien für die Anlage von Straßen, Teil: Linienführung RAS-L” 1995 [155], the intersections of the lines drawn horizontally or vertically for the radius of curves for the three inconsistent transitions, indicate the points which fall on the relation design curves for “poor design” (transition no. 1) and are not involved (transition no. 2 and no. 3).

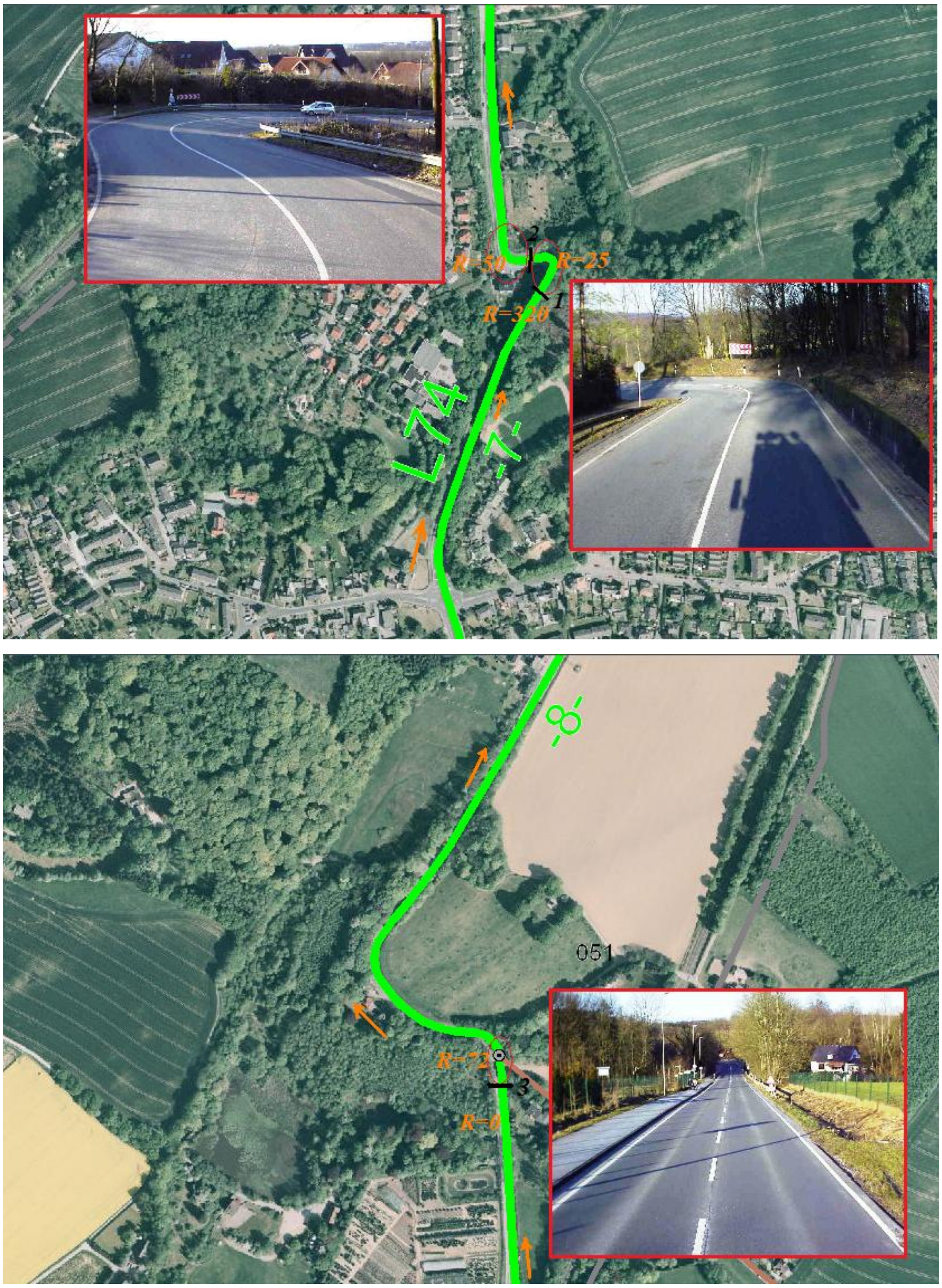


Figure 5.8: Plan view for the three inconsistent transitions alignments [113].

5.5.4 Traffic analysis model evaluation results

TWOPAS is a microscopic computer simulation used as model for a collection of software analysis tools for evaluating safety and operational effects of geometric design decisions on two-lane rural highways in IHSDM.

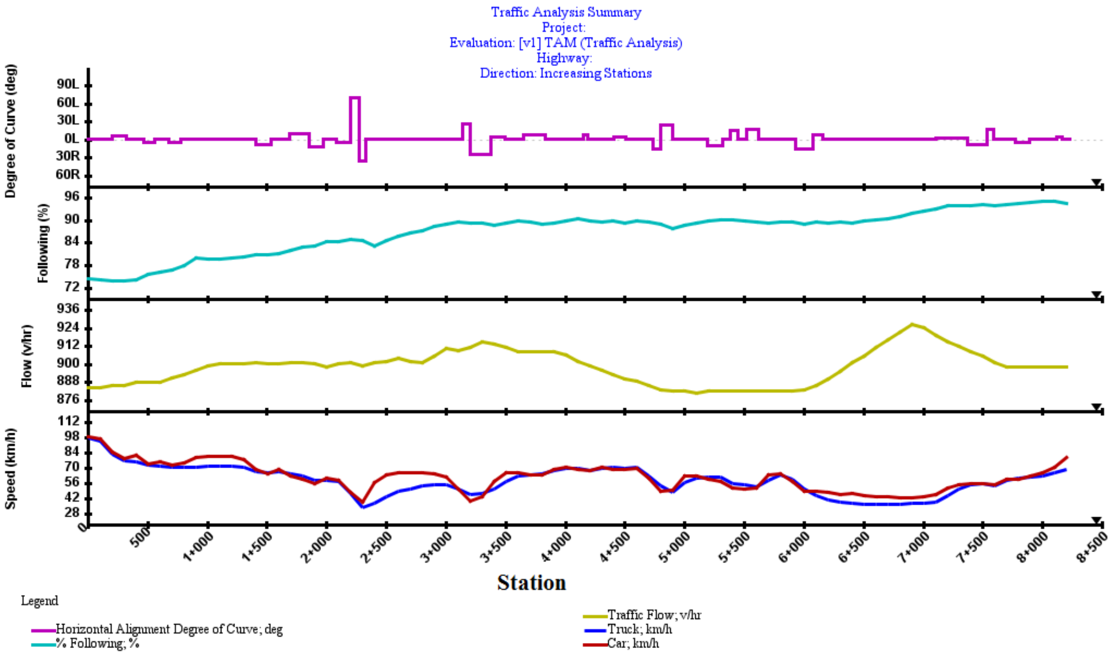
Two performance measures are used to describe service quality for two-lane highways: percentage of time-spent-following (PTSF), and average travel speed (ATS) [156]. According to HCM 2000 [156], PTSF is defined as the average percentage of travel time that vehicles must travel in platoons behind slower vehicles because of the inability to pass, while ATS is defined as the length of the highway segment divided by the average travel time of all vehicles traversing the segment, including all stopped delay times.

Referring to the PTSF and ATS values in the Table 5-6, the high percent of PTSF and low value of ATS means that the platooning becomes intense when slower vehicles or other interruptions are encountered, and also represents low freedom to maneuver, as well as the comfort and convenience of travel.

Table 5-6: TAM traffic output data.

Traffic Output Data	**Direction of travel**		
	Increasing station	**Decreasing station**	**Combined**
Flow rate from simulation, v/hr	900	1,425	2,325
Percent time spent following, %	88.2	90.2	**89.4**
Average travel speed, km/h	56	55	**55**
Trip time, min/veh	8.8	9.0	8.9
Traffic delay, min/veh	2.36	2.79	2.62
Geometric delay, min/veh	1.38	1.21	1.28
Total delay, min/veh	3.75	4.00	3.90
Number of passes	8	175	183
Vehicle km traveled	7,370	11,678	19,048
Total travel time, veh-hrs	131.4	214.3	345.7

Figure 5.9 illustrates a traffic analysis summary graph. This graph includes plots of degree of curve, percent following, flow rate, and mean speed.



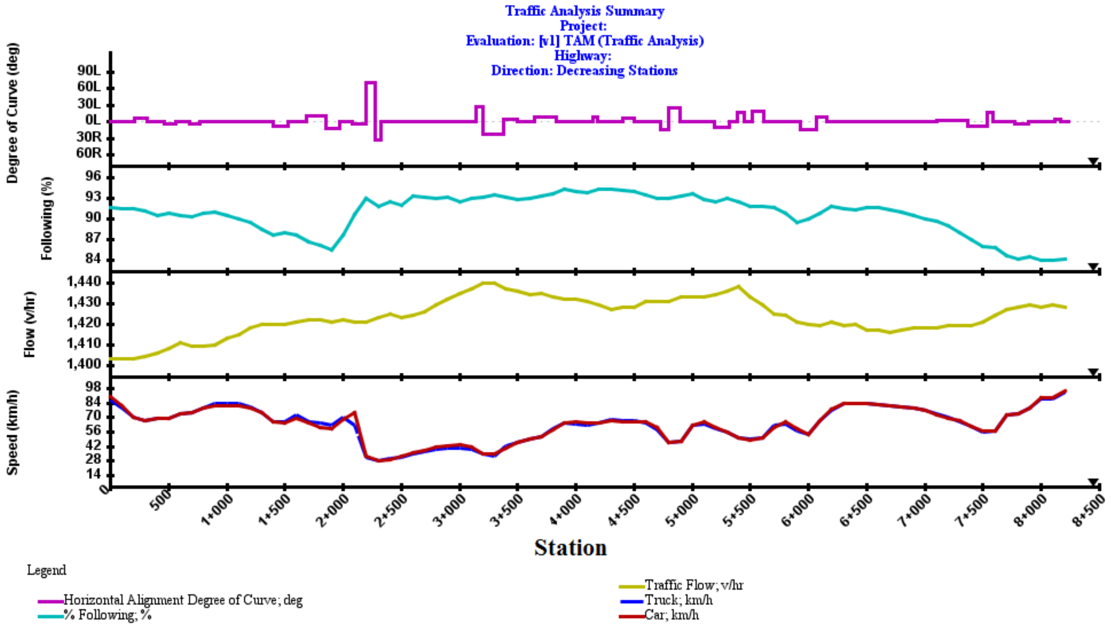


Figure 5.9: Traffic analysis summary graph (increasing and decreasing stations).

5.5.5 Driver/vehicle model evaluation results

The DVM, which is a time-based simulation model, estimates the vehicle's speed and path along a two-lane rural highway in the absence of other traffic [152]. These estimates provide for various computational performance measures, such as lateral acceleration, friction demand, and rolling moment. Driver performance is influenced by cues from the roadway and vehicle system (i.e. drivers modify their behavior based on feedback from the vehicle and the roadway). Vehicle performance is, in turn, affected by driver behavior and performance.

The output report shows graphs of several variables over the length of the roadway (see Figure 5.10). The graphs of vehicle speed and lateral acceleration are very helpful. "Lateral Acceleration" is the lateral acceleration of the vehicle in g's due to turning; that is, the acceleration along the axis of the vehicle perpendicular to the direction of motion. It does not include the gravitational effects of the cross slope (i.e. road crown). Thus, lateral acceleration is defined in the plane of the earth rather than the plane of the road. A positive sign is assigned to the lateral acceleration when the road curve is turning to the right; a negative sign is assigned when the road curve is turning to the left.

The maximum lateral acceleration is what the driver willingly tolerates in a horizontal curve. By assuming that truck drivers are adopting maximum lateral accelerations that are less than the rollover threshold (i.e. the lateral acceleration that would cause the truck to tip over), the ratio of maximum allowable acceleration to rollover threshold provides a measure of rollover stability in a turn. On-road studies indicate that the relative stability is not constant, but varies with the loading on the truck. Specifically, drivers appear to tolerate a larger lateral acceleration relative to rollover threshold (and therefore greater risk of rollover) for loaded trucks compared to unloaded trucks [152]. The boundaries of friction ratio X (longitudinal skid index) and friction ratio Y (lateral skid index) are +/- 1. The boundary conditions indicate that the vehicle is right on the edge of skidding, where the sign indicates the direction of such skidding.

- A positive longitudinal friction ratio indicates that increasing the grade value reduces the longitudinal force experienced by the vehicle. (For upgrades (+), increase means steeper grade; for downgrades (-), increase means less steep.) Likewise, a negative longitudinal friction ratio indicates that decreasing the grade value reduces the longitudinal force experienced by the vehicle.

- A positive lateral friction ratio indicates that rotating the road cross-section clockwise reduces the lateral skidding tendency. A negative lateral friction ratio indicates that rotating the road cross-section counterclockwise reduces the lateral skidding tendency.

The rollover index is the lateral load transfer indicating the fraction of vehicle weight borne by the right or left tires. It is slightly more intuitive, but there is no indication of what values should raise concern. While it is obvious that a rollover index value of 0.5 indicates a greater likelihood that the vehicle will roll over than a rollover index value of 0.3, it still does not indicate what the likelihood is.

The path variable, which is the lateral offset from lane center (a positive value indicates a displacement to the right of lane center, and a negative value indicates a displacement to the left of the lane center) is also helpful. The driver has a lateral offset towards the outside of the curve before he is able to regain his intended path and cut to the inside of the curve, which is consistent with the driver not expecting the horizontal curve.

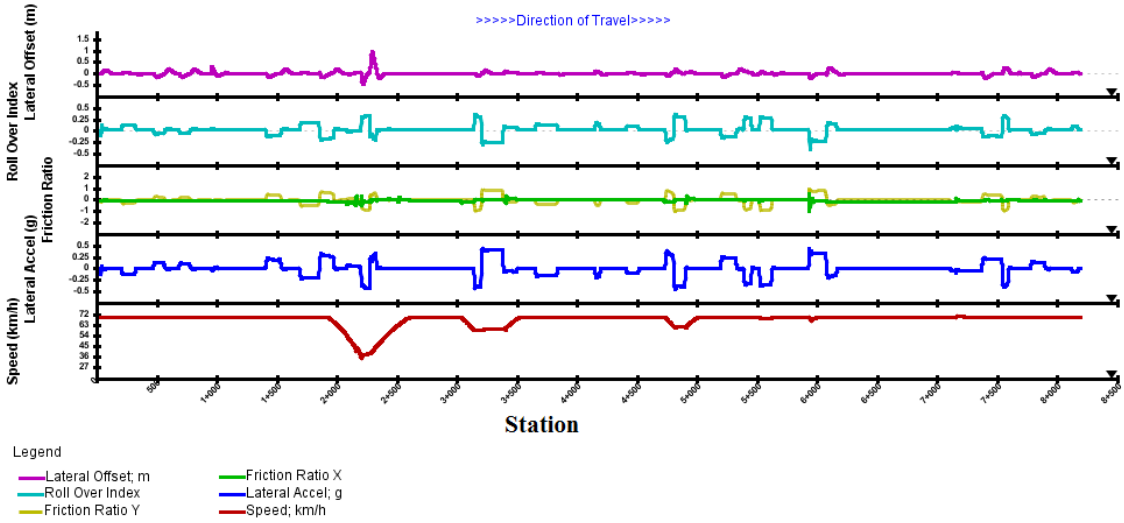


Figure 5.10: DVM simulation run graph.

5.6 Adaptation of IHSDM to Germany

Because of the wide variety of design practices and road environments within the USA, IHSDM was deliberately designed to allow for local customization, e.g. by state. Already other countries (e.g. Canada, Spain and New Zealand) [135-137] have recognized the ability to customize it. Therefore, IHSDM appears to be a suitable tool for use in safety analyses in Germany.

A number of tasks have been required to make IHSDM appropriate for German conditions, including:

- calibrating the crash prediction model to reflect local patterns;
- incorporating a set of Germany-specific design policies and standards;
- and developing a means of importing existing road geometry and crash data into IHSDM.

5.6.1 Calibration of crash prediction model

A calibration procedure is provided for adapting the predicted CPM results to the safety conditions encountered by any particular highway agency. Section 5.4.2 describes in detail the underlying crash prediction model used in IHSDM's CPM. This process allows for the adjustment of three factors:

- an overall "calibration factor": a scaling factor to adjust the overall crash numbers;
- modification of the relative proportions of crashes by injury severity;
- and modification of the relative proportions of crashes by crash type.

IHSDM provides spreadsheet templates to assist with the derivation of suitable calibration factors for any given state. The spreadsheet compares the default predicted number of crashes with the actual recorded crashes, adjusted for the relative traffic volumes and total kilometers on roads with different geometries (gradient, curvature, lane width, etc).

Using the database analysis work described in Section 3.3, the crash data on these highways have been summarized to produce local calibration values for the CPM. All of the IHSDM calibration inputs are specified in Imperial or US customary units (miles, feet); therefore conversion routines were required to scale the German data given in kilometers and meters.

It is important to remember that the ability to directly include historical crash data within IHSDM also helps to calibrate the model to local conditions; the calibration factor is used to scale up the prediction model to better fit the observed data.

5.6.1.1 Crash prediction model calibration factors

The calibration procedure is implemented by a highway agency by determining the value of the calibration factor for roadway sections from comparison of history accidents data to estimates from the accident prediction algorithm. A calibration procedure is provided to allow individual highway agencies to adapt the algorithm to the safety conditions present on the rural two-lane highway system. The calibration procedure allows IHSDM users to adjust the predicted accident frequencies for agency-to-agency and state-to-state differences in factors such as accident reporting thresholds, accident reporting practices, animal populations, driver populations, and climates.

The IHSDM calibration spreadsheets were used to determine a scaling factor to adjust the overall crash numbers. This was based on a dataset of over 2,767 reported non-intersection crashes on Landkreis Mettmann during 2000-2005 and 1,546 crashes on Wuppertal, Solingen and Remscheid Kreisfreie Städte during 2002-2004. The highway data available contains traffic count data from 1990, 1995 and 2000. Therefore, generic scaling factors were used to convert the traffic volumes to the 2003 estimated AADTs (i.e. the midpoints of each period), to reflect the change in traffic exposure during each period.

Appendix III describes the database and spreadsheet processing steps required to determine suitable calibration factors. Table 5-7 summarizes the calibration factors determined for two regions within the case study; each calibration factor is the ratio of the observed crash numbers in case study to the predicted crash numbers from IHSDM’s calibration spreadsheet. The calibration factors, Cr, had values less than 1.0 for two regions within the case study, i.e. these roadways experienced fewer accidents than the roadways used in the development of the accident prediction algorithm. The results suggest that the accident numbers in Germany are lower than those observed in the USA.

Table 5-7: IHSDM calibration factors for case study.

Crash analysis	**Landkreis Mettmann (2000-05)**	**Wuppertal, Solingen and Remscheid Kreisfreie Städte (2002-04)**
Observed Crashes No.	2767	1546
Predicted Crashes No.	3462	1755
Calibration Factor, Cr	0.80	0.88

5.6.1.2 Modification of the relative crash severity proportions

The default IHSDM crash severity proportions are based on Highway Safety Information System (HSIS) data for Illinois, Michigan, Minnesota, and North Carolina in the mid-1990s [118]. The default distributions for accident severity and accident type can be replaced with data suitable for the rural two-lane highway system of a particular highway agency as part of the calibration process. A similar analysis was undertaken for Germany's injury and non-injury crash data from included case study sections (excluding intersection crashes) in the research database (the detailed description in Section 3.4.2). Table 5-8 summarizes the respective proportions for Landkreis Mettmann (2000-05) and Wuppertal, Solingen and Remscheid Kreisfreie Städte (2002-04).

Table 5-8: Percentage distributions for crash severity level.

Crash severity level	**IHSDM defaults**	**Landkreis Mettmann values 2000-05**	**Kreisfreie Städte Wuppertal, Solingen and Remscheid values 2002-04**
Fatal	1.3%	0.5%	0.5%
Incapacitating injury	5.4%	6.3%	3.8%
Non-incapacitating injury	10.9%	13.7%	12.2%
Possible injury	14.5%	-	-
Total fatal plus injury	32.1%	20.5%	16.5%
Property damage only	67.9%	79.5%	83.5%

Fatal crash percentages are about twofold lower than the reported crashes as in the IHSDM defaults. One could speculate that this reflects a greater propensity to report crashes of lesser severity in Germany.

It is recommended that users of the accident prediction algorithm replace the default accident severity distribution shown in Table 5-8 with values specifically applicable to the rural two-lane highways under a particular agency's jurisdiction.

One notable observation of the existing IHSDM crash prediction process is that the same crash severity proportions given in Table 5-8 are applied to all road section estimates of crash numbers. This seems somewhat unrealistic, as the average severity is likely to be affected by the crash type and surrounding environment. For example, a greater proportion of head-on crashes are likely to lead to relatively more fatal or serious injury crashes. Similarly, a road environment with more severe roadside hazards (e.g. non-frangible trees) or where higher vehicle operating speeds can be expected is also likely to experience more severe crashes on average.

The only situation where crash severity is taken into account in IHSDM is in the Empirical Bayes analysis, where property-damage-only and fatal and injury crash estimates are calculated separately based on the relative numbers of observed crashes in each case.

5.6.1.3 Modification of the relative crash type proportions

The default IHSDM crash type proportions are also based on the same HSIS data as before. Again, an analysis of crash types was undertaken using Germany’s injury and non-injury crash data from included case study sections.

An initial difficulty was determining which crashes in the German data equated to which IHSDM categories. This was made somewhat complicated because of the mixed methods for categorizing crashes in the US system. For example, while some crash types are by vehicle movement (e.g. “angle collision”, “ran-off-road”, etc), others are categorized by the parties involved (e.g. collision with animal, parked vehicle, etc), or the resulting outcome (e.g. “overturned”). Thus, a simple translation table was not easy to achieve without a series of database processing steps. Even then, it is acknowledged that a perfect translation is not likely. For example, FGSV 316/1 “Merkblatt für die Auswetung von Strassenverkehrsunfällen” [119] does not show specifically whether a vehicle overturned. It is however probably reasonable to relate this category to “lost control on road” crashes, which is the usual cause of such single-vehicle overturning events. Therefore, the lost-control crash numbers in Germany are compared with the combined proportion of "ran-off-road" and "overturned" crashes. The key linkages between IHSDM and Germany categorization systems are summarized in Table 3-1.

This is only an issue for comparison purposes; for use in IHSDM, it is only important that the user knows what the reported categories refer to in terms of the assigned German crash types. It is certainly not recommended that Germany should adopt a similar system to the US for its crash type coding, as there appear to be few advantages for general road safety research and analysis in doing this. As discussed in Section 3.1, only intersection related crash types located at intersections have been removed from the analysis. This still leaves similar crashes that have occurred at other mid-block locations (such as driveways) remaining in the dataset.

As shown in Table 5-9, the relative proportions of single- and multiple-vehicle crashes are different. There are some discrepancies between the proportions within each subcategory. As discussed above, some of this is due to differences in the definitions for each category within the US and German crash data.

There is however a notable difference in the proportion of single-vehicle collisions involving animals, which is not as prevalent a hazard in Germany. With regards to multiple-vehicle crashes, the biggest difference is in the proportion of head-on crashes; although it is speculated that some of these in the data for Germany would have been coded “sideswipe” under the US system. The other difference appears to have been made up by a notable increase in the proportion of "rear-end" crashes reported in Germany, as the coding for these appears more straightforward. However it is possible that a number of crashes with Crash Type 2 and Crash Type 7 codes could also physically result in a rear-end collision.

The default distributions for accident type can be replaced with data suitable for the rural two-lane highway system of a particular highway agency as part of the calibration process. Use of distributions applicable to a specific state or geographic region is particularly appropriate because some of the percentages in the Table 5-9, such as the percentage of animal-related accidents on roadway segments in Table 5-9, clearly vary geographically.

Table 5-9: Percentage distributions for crash types.

IHSDM Crash Type	IHSDM defaults	Values 2000-05	Values 2002-04
single-vehicle crashes			
Collision with animal	30.9%	13.6%	13.6%
Collision with parked vehicle	0.7%	2.1%	1.9%
Overturned	2.3%	-	-
Ran off road	28.1%	-	-
Overturned + Ran off road	30.4%	24.2%	21.6%
Other single-vehicle collision	4.3%	2.5%	4.5
Total single-vehicle crashes	*66.3%*	*42.4%*	*41.6%*
multiple-vehicle crashes			
Angle collision	3.9%	2.1%	2.4%
Head-on collision	1.9%	11.6%	2.4%
Left-turn collision	4.2%	13.6%	7.8%
Right-turn collision	0.6%	4.3%	5.2%
Rear-end collision	13.9%	20.0%	29.8%
Sideswipe collision	5.0%	2.5%	5.8%
Other multiple-vehicle collision	4.1%	3.5%	5.0%
Total multiple-vehicle crashes	*33.7%*	*57.6%*	*58.4%*

The accident type distributions for roadway segments in Table 5-9 should be calibrated in this manner using the same accident data used to update Table 5-8. It should be noted that the accident type distribution for roadway segments influences the AMFs for lane width, shoulder width, and shoulder type presented in section 5.4.2 and Appendix IV.

As with crash severity, another key issue is the fact that the respective crash type proportions are fixed for all IHSDM analyses, regardless of the environment being investigated. The relative proportions of crash types are likely to vary at least with regards to traffic volumes and the curvature of the road. At the very least it would be desirable to determine a relationship in IHSDM between the expected proportions of single-vehicle and multiple-vehicle crashes, with the respective crash subtypes in each category scaled accordingly.

It is possible for a highway agency to use the accident prediction algorithms without calibration, but this is not recommended. Using the accident prediction algorithm without calibration requires the user to accept the assumption that for their agency Cr = 1.0 and the accident severity and accident type distributions for two-lane highways are those shown in Tables 5-8 and 5-9, respectively. These assumptions are unlikely to be correct for any highway agency and are unlikely to remain correct over time. By using the calibration it is more likely that satisfactory results will be produced than when using the algorithm without calibration.

5.6.2 Editing design policy files

IHSDM is currently provided with US Federal standards and guidelines (e.g. AASHTO 2001) on which to base its decisions about design consistency and policy compliance (as used in the PRM and DCM models). These, however, are specified in external files, and the program is designed to be able to accept alternative criteria such as state department or local design policies. IHSDM's System Administration Tool allows users to create or edit policy files to use with the program.

5.7 Chapter summary

The study sections selected for analysis were all two-lane rural highways, which were the target study type of roads for IHSDM. By a focus on one highway section as an example, the results of analysis for IHSDM concluded that IHSDM makes it significantly easier and faster to evaluate design decisions. Each model focuses on a specific area of analysis.

The policy review model checked roadway-segment design elements against design guidelines (AASHTO 2004) and provided an initial assessment of how the geometric design compares to design guidelines. This model showed comments for cross-section, horizontal alignment, vertical alignment, and sight distance, in order to provide guidance by referencing a recommended range of values for critical dimensions. It also showed that the available SSDs vary along the highway sections and 45% of the sections were less than the minimum required SSD, and that available PSDs are generally less than the minimum required PSD. These values, however, are specified in external files, and the program is designed to be able to accept alternative criteria such as state department or local design policies.

The crash prediction module estimates the frequency of crashes expected on a roadway based on its geometric design and traffic characteristics. The algorithm for estimating crash frequency combines statistical base models, calibration factors and accident modification factors AMFs. The accident modification factors adjust the base model estimates for individual geometric design element dimensions and for traffic control features. The algorithm can be calibrated by state or local agencies to reflect roadway, topographic, environmental, and crash-reporting conditions. The algorithm also provides an Empirical Bayes procedure for a weighted averaging of the algorithm estimate with project-specific crash history data.

The CPM analysis was undertaken both with and without the local crash history being incorporated (using Empirical Bayes), and showed that the expected crashes rate (with crash history) had high correlation with the observed crashes. In contrast, the expected crashes rate without crash history data is higher than the observed crashes rate. Indeed, using crash history data appears to provide a better level of "local calibration" than attempting to derive specialized calibration parameters, and requires far less effort. The CPM is more useful in identifying high crash locations than estimating specific crash frequency or rates and the assessment of the road elements that are causing the crashes.

The design consistency module helped diagnose safety concerns at horizontal curves. Crashes on two-lane rural highways are over-represented at horizontal curves, and speed inconsistencies are a common contributing factor to crashes on curves. This module provides estimates of the magnitude of potential speed inconsistencies. The design consistency module uses a speed-profile model that estimates 85th percentile, free-flow, passenger vehicle speeds at each point along a roadway. The speed-profile model combines estimated 85th percentile speeds on curves (horizontal, vertical, and horizontal–vertical combinations), desired speeds on long tangents, acceleration and deceleration rates exiting and entering curves, and an algorithm for estimating speeds on vertical grades. The module identifies two potential consistency issues: *1)* large differences between the assumed design speed and estimated 85th percentile speed (design consistency), and *2)* large changes in 85th percentile speeds from an approach tangent to a horizontal curve (operating speed consistency).

The DCM analysis showed that the design consistency is good; this indicates a well-balanced design or good curvilinear alignment. According to the operating speed consistency, there are three poor transitions, i.e. a change of more than 20 km/h in operating speeds would certainly result in an unbalanced design or a critical alignment.

The Traffic Analysis Model estimated the operational effects of designs under traffic flows, e.g. travel times, time spent following, and vehicle interactions. Two performance measures were used to describe service quality for two-lane highways: percent time –spent following (PTSF) and average travel speed (ATS). TAM analysis showed the high percent of PTSF and low value of ATS, i.e. the platooning becomes intense as slower vehicles or other interruptions are encountered, and also represents low freedom to maneuver, as well as the comfort and convenience of travel.

The Driver Vehicle Module (DVM) is used to evaluate how a driver would operate a vehicle within the context of a specific roadway design and to identify whether conditions exist within that design that could result in the loss of vehicle control. The DVM couples a vehicle dynamics model with a computational model of driver behavior. This model of driver behavior aims to simulate the driver's perceptual, cognitive, and control processes to generate steering, braking, and throttle vehicle inputs.

The output report showed graphs of several variables over the length of the roadway. The graphs of vehicle speed and lateral acceleration are very helpful, but Friction Ratio X and Y are not common terms that are particularly meaningful to a highway engineer. The rollover index is slightly more intuitive, but there is no indication of what values should raise concern. While it is obvious that a rollover index value of 0.5 indicates a greater likelihood that the vehicle will roll over than a rollover index value of 0.3, it still does not indicate the likelihood. The lateral offset variable is also helpful, but it is unclear what the offset is measured from and which side of the roadway corresponds with positive and negative values.

However, a number of tasks have been identified to make IHSDM suitable for use here, including:

- calibrating the crash prediction model with German crash patterns;
- developing a German Design Policy file based on local agency standards and guidelines;
- and developing an importing routine for Germany's highway geometry data.

Some of the two-lane rural road sections were tested in IHSDM to assess its crash prediction abilities and other related features, i.e. the remaining modules. These investigations have shown that IHSDM is a promising tool for safety and operational assessment of highway alignments in Germany.

A calibration procedure is provided for adapting the predicted CPM results to the safety conditions encountered by any particular highway agency. This process allows for adjustment of three factors:

- a scaling factor to adjust the overall crash numbers;
- modification of the relative crash severity proportions;
- and modification of the relative crash type proportions.

The results of the crash prediction calibration highlighted that the calibration factors, Cr, had values less than 1.0 for two regions within the case study, i.e. these roadways experienced fewer accidents than the roadways used in the development of the accident prediction algorithm. The results suggested that the accident numbers in Germany are lower than those observed in the US. The data for Germany also indicated that ~80% of reported crashes are non-injury (property-damage-only), which is higher than the default IHSDM crash model. Meanwhile, IHSDM predicted only 1.3% of all mid-block crashes have fatalities, whereas the equivalent German data gave a figure around two-fold lower than that. One could speculate that this reflects a greater propensity to report crashes of lesser severity in the Germany. Also, the relative proportions of single- and multiple-vehicle accidents were different. There were some discrepancies between the proportions within each subcategory due to differences in the definitions for each category within the US and German crash data. For example, the default IHSDM crash model assumes that ~30%

of rural mid-block crashes involve collisions with animals. This is much higher than found in the German rural highways (13.6%).

Finally, IHSDM does not provide any information about the economic assessment for the analysis and treatment.

6 Conclusions

6.1 Review of research objectives

It is pertinent here to review the stated objectives of this research, as given in Section 1.3:

1. To identify road factors affecting accidents on rural roads;
2. To analyze the rural roads based on Network Safety Management (NSM) to find measures that have the highest accident reduction potential, i.e. to consider the parts of the network where the most can be gained in relation to the cost;
3. To assess the accident risk by using Algorithm (mapping "NSM" and statistical techniques "cluster analysis");
4. To identify the tasks required to adapt IHSDM for use in Germany and to undertake the necessary adaptations;
5. To assess the effectiveness of IHSDM in Germany for predicting the relative safety of a rural road;
6. And to compare among the three methods (Preliminary & Regression Analyses, NSM and IHSDM).

The discussions below assess the success in meeting these original objectives and any resulting conclusions.

1. Road factors affecting accidents on rural roads

Preliminary and regression analyses were conducted between accident rates and each geometric design characteristic. The purpose of these analyses was to investigate the trend of the relationships between road parameters and accidents rate.

A detailed accident analysis in the study area showed that around one fourth of the accidents (23%) are running-off-the-road accidents. Also, injury accidents as a whole accounted for close to 19% of all accidents, and the larger proportion of fatal and injury accidents involve run-off accidents (higher severity) compared to other collision types. We therefore need to reduce accident risk as far as possible. Strategies to improve safety due to run-off crashes include improving pavement marking visibility; installing rumble strips along lane delineators; installing safe roadside hardware such as guard rails, curbs, and drainage gates; where possible removing poles and trees from the side of the road; improving ditch and side-slope designs to minimize rollovers and impact; and installing centerline rumble strips on two-lane highways.

The analysis of correlation highlighted that the correlations were relatively low, because there is a relatively high dispersion of the data. This was expected, since crashes happen as a result of numerous and different factors, with each factor contributing differently to the occurrence of a crash. Moreover, these factors and their relative contribution typically change from one crash to another.

The results of the analysis generally agreed with engineering intuition. They highlighted that accident rates increase quickly with radii less than 500 m (a cross-point in safety) and it is stable for radius more than 850 m (very small improvements in traffic safety). It is clear that curves were significantly responsible for accidents; 90% of accidents occurred on horizontal curves sections, where 57% of the sections had curves, because of the increased demands placed on the driver and vehicle. The analysis results are again intuitively expected; wider lanes result in reduced accidents. Roads with lanes of 4 m or wider have lower accident rates than roads with 3 m lanes (80% of two lanes rural in area study have lane width less than 3 m). Another examination that was conducted during the analysis evaluated the relationship between accidents rate and the average daily traffic volumes on the roads studied. This relationship was expected to be non-linear as some researchers have suggested. The accident rates also have a positive relationship with the grade, driveway density and roadside hazard rating.

2. Analysis of rural roads based on network safety management (NSM)

The aim of this analysis is to understand the dysfunctions of the road before implementing countermeasures and to adapt solutions to the specific nature of each encountered road and context. Once a high-risk road section has been dealt with, the safety quality of the whole network may be improved. Assessments could range from identifying and treating accident patterns at single high-risk sections to understanding and managing safety over whole routes.

As a result of ranking sections by their potential savings in accident costs in the study area, the analysis revealed that the safety potential of the huge section is about 642 10^3 €/ (km*y). Based on the detected conspicuous accident patterns and its analysis, suitable countermeasures should be derived. Head-on and run-off accidents were common on this section. The countermeasures that might reduce the potential for these accident types are improving delineation, erecting crashworthy barrier systems on medians or roadside and/or guardrail barriers, applying the rumble strip along edge- or centerline, and making geometric improvements.

Finally, the efficiency of the countermeasures should be assessed. It will then be possible to compare the potential savings in accident costs with the costs for countermeasures in order to rank measures by their priority.

3. Application of the accident risk assessment algorithm

The algorithm provided both statistical (i.e. cluster analysis) and geographical information (i.e. NSM) on the accident events. The algorithm helps to identify factors that have significant influence on accidents, and to identify the road sections that have high accident risk. The results show that the algorithm provides more information of accident risk when compared to the risk base on the historical accident records.

By using a mapping technique, we could assess the relationships between the risks of the different road sections and geometric design characteristics, such as grade, radius, lane width, driveway density, roadside hazard rating, and traffic volume. It was found that the distribution of the accidents density and accidents cost density were different, while the high accidents rate was concentrated in Velbert, Wuppertal and Remscheid cities. In addition, there were high traffic volumes (greater than 7500 veh/d), bad roadsides, flat terrain, and a variety radius and lane widths for most of the sections.

By using cluster analysis, the road sections were disaggregated into three clusters by referring to the accidents cost rate (ACR) distribution. Cluster 1 can be considered as the sections having high lane width, high driveway density, high radius, more safe roadside, low grade and high traffic volume, while Cluster 3 can be considered as the sections having opposite characterizations of Cluster 1. Cluster 2 is the middle of the best section characterizations (Cluster1) and worst (Cluster 3).

However, the results of the cluster analysis contain useful information that can provide interesting insights into the various accident-road element relationships, which are lost when reducing each cluster to a short one-sentence description.

4. Identification of tasks required to adapt IHSDM to Germany

A number of tasks were identified to make IHSDM suitable for use in Germany. The crash prediction model was calibrated to match Germany crash patterns. The crash history data appears to provide a better level of calibration.

A set of Germany-specific design policies and standards have to be developed for using within the program. Importing routines have to be developed to export highway geometry and accident data from the highway database into formats suitable for use in IHSDM.

5. Validation of IHSDM to local data

Some two lane rural roads in North Rhine Westphalia were tested in IHSDM to assess its safety performance. The initial investigations have shown that IHSDM is a promising tool for safety and operational assessment of highway alignments in Germany. Where possible, incorporating crash history data generally improves the precision in crash number estimates.

A calibration procedure is provided for adapting the predicted CPM results to the safety conditions encountered by any particular highway agency. This process allows for adjustment of three factors:

- a scaling factor to adjust the overall crash numbers;

- modification of the relative crash severity proportions;
- and modification of the relative crash type proportions.

The results of the crash prediction calibration highlighted that the calibration factors, Cr, had values of less than 1.0 for two regions within the case study, i.e. these roadways experienced fewer accidents than the roadways used in the development of the accident prediction algorithm. The results suggested that the accident numbers in Germany are lower than those observed in the US. The German data also indicated that ~80% of reported crashes are non-injury (property-damage-only), which is higher than the default IHSDM crash model. Meanwhile, IHSDM predicted that only 1.3% of all mid-block crashes have fatalities, whereas the equivalent German data gave a figure about two times lower. One could speculate that this reflects a greater propensity to report crashes of lesser severity in the Germany. Also, the relative proportions of single and multiple vehicle accidents were different. There were some discrepancies between the proportions within each subcategory due to differences in the definitions for each category within the US and German crash data. For example, the default IHSDM crash model assumes that ~30% of rural mid-block crashes involve collisions with animals. This is much higher than that found in Germany's rural highway (13.6%).

6. Comparison among the three methods (preliminary & regression analyses, NSM and IHSDM)

I- Preliminary and regression analyses

The data analysis sought to understand accident rates, severity, risk trends and the relationships between road parameters and accidents characteristics.

In conclusion, preliminary analyses are particularly likely to be preferable when the models are adequate and the important variables can be identified before any of the modeling efforts. For example, any correlation in the data set, including correlation among the independent and dependent variables, should be identified before moving to the modeling step. However, when dealing with a large and complex data set of road accidents, the use of preliminary analysis seems particularly useful to identify the relevant variables that make a strong contribution towards a better understanding of accident causality.

II- NSM

Network Safety Management (NSM) describes a methodology for analyzing road networks from the traffic safety point of view and detecting the sections within the network with the highest safety potential, i.e. where an improvement of the infrastructure is expected to be highly cost efficient. Suitable measures can then be derived from a comprehensive analysis of the accidents. The safety potential and the calculated cost of the measure form the basis for an economic assessment, which is usually conducted as a cost–benefit analysis.

Therefore, only the described NSM methodology provides all the necessary information for an objective assessment of road safety and an establishment of a ranking of sections for further analysis and treatment. This ensures that the limited resources are spent in the best way to improve road safety for the whole society.

III- IHSDM

IHSDM is a useful tool for evaluating safety and operational effects of geometric design decisions on two-lane rural highways. IHSDM makes it significantly easier and faster to evaluate design decisions. Each model provides different measures of the expected safety performance of an existing or proposed highway geometric design, since each model focuses on a specific area of analysis. The policy review model automates the current process of checking a design against applicable, quantitative design guidelines. The crash prediction model provides quantitative safety performance measures, including expected crash frequency and severity. The design consistency evaluations supply a greater degree of efficiency and objectivity in identifying alignment defects which affect road safety. The remaining models diagnose factors contributing to safety performance of a proposed design.

In general, it can be concluded that:

I- The use of preliminary analysis is useful for identifying the relevant variables that make a strong contribution towards a better understanding of the relationships between road parameters and accidents characteristics.

II- NSM can be an important element of the cost efficient safety analysis if the accident data and statistics are available (for existing roads). Assessments could range from identifying and treating accident patterns at single high-risk sites to understanding and managing safety over whole routes.

III- IHSDM provides safety information on the relationships between geometrics design and accidents in a usable format, and guide the designer in evaluating the safety of propose or alternative alignments. IHSDM do not provide any information about the economic assessment for the analysis and treatment

6.2 Future research

- This research has focused on the mid-block (non-intersection) aspects of rural road safety performance. It would be of value to investigate the ability of IHSDM to evaluate the safety of intersections on rural two-lane roads in Germany.
- IHSDM's crash type and crash severity estimates are of limited use in their current form, as the default values are consistently applied across all road sections. It would be desirable for some basic relationships to be included in IHSDM that adjusted the default proportions for crash type and severity to account for road environment factors such as traffic volume, number of lanes, design speed, horizontal curvature and roadside hazards.
- The use of crash data related with road environment factors requires an accurate understanding of the location of each crash. For future research, it would be of immense value to accurate crash location identification.

6.3 Recommendations

IHSDM in its current form does not incorporate pavement condition. It is worth considering in any future crash risk modeling using a variable-length element database as used in this research. It may be that pavement condition is more relevant to curve elements or rear-end accidents on straight elements.

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Appendices

Appendix I: Descriptive Statistics

Table I-61: Descriptive statistics - geometric characteristics.

	Minimum	**Maximum**	**Sum**	**Mean**	**Std. Deviation**
Subsection length, km	0.400	1.810	**250.216**	0.532	0.152
Lane width, m	2.30	5.75		3.46	0.47
Roadside hazard rate	1	7		5.7	0.8
Driveway density, driv./km	0	6	689	1.47	1.361
Radius, m	20	2600		375.72	334.9
Grade, %	1.0	14.0		3.5	1.9
Traffic volume, veh/h	1474	24775		7886.6	4493.3

Table I-2: Descriptive statistics - accidents types.

	Minimum	**Maximum**	**Sum**	**Mean**	**Std. deviation**
subsection accident		59	**4312**	9.7	8.9
Single Vehicle Accident		35	1677	4.2	4.3
Multi Vehicle Accident		56	2635	6.6	6.6
Angle	1	6	94	1.3	0.7
Animals	1	17	587	2.4	2.0
Head-on	1	19	357	2.1	2.6
Left-turn	1	12	498	2.0	1.8
Other	1	12	313	1.7	1.3
Parked	1	3	87	1.4	0.7
Ran-off	1	34	1003	3.4	3.9
Rear-end	1	36	635	2.9	3.8
Right-turn	1	33	578	3.1	4.2
Sideswipe	1	10	160	1.6	1.2

Table 6-3: Descriptive statistics - accidents severity.

	Maximum	**Sum**	**Mean**	**Std. deviation**
Subsection accident, km	59	**4312**	9.7	8.9
Fatal	1	20	0.6	.5
Serious Injury	7	232	1.5	1.1
Light Injury	10	568	2.1	1.5
Property-Damage-Only	54	3492	8.0	7.5

Apendix II: Definitions of Roadside Hazard Ratings (RHR)

The accident prediction algorithm uses a roadside hazard rating system developed by Zegeer, et al. to characterize the accident potential for roadside designs found on two-lane highways [116]. Roadside hazard is ranked on a seven-point categorical scale from 1 (best) to 7 (worst).

The seven categories of roadside hazard rating are defined as follows:

Rating 1: where, 1) wide clear zones greater than or equal to 9 m from the pavement edgeline, 2) sideslope flatter than 1:4 and 3) recoverable, as shown in Figure II.1.

Figure II.1: Typical roadway with roadside hazard rating equal to 1.

Rating 2: where, 1) ***c***lear zone between 6 and 7.5 m from pavement edgeline, 2) sideslope about 1:4 and 3) recoverable, as shown in Figure II.2.

Figure II.2: Typical roadway with roadside hazard rating equal to 2.

Rating 3: where, 1) clear zone about 3 m from pavement edgeline, 2)sideslope about 1:3 or 1:4, 3) rough roadside surface and 4) marginally recoverable, as shown in Figure II.3.

Figure II.3: Typical roadway with roadside hazard rating equal to 3.

Rating 4: where, 1) clear zone between 1.5 and 3 m from pavement edgeline, 2) sideslope about 1:3 or 1:4, 3) may have guardrail (1.5 to 2 m from pavement edgeline), 4) may have exposed trees, poles, or other objects (about 3 m or from pavement edgeline) and 5) marginally forgiving, but increased chance of a reportable roadside collision, as shown in Figure II.4.

Figure II.4: Typical roadway with roadside hazard rating equal to 4.

Rating 5: where, 1) clear zone between 1.5 and 3 m from pavement edgeline, 2) sideslope about 1:3, 3) may have guardrail (0 to 1.5 m from pavement edgeline), 4) may have rigid obstacles or embankment within 2 to 3 m of pavement edgeline and 5) virtually non-recoverable, as shown in Figure II.5.

Figure II.5: Typical roadway with roadside hazard rating equal to 5.

Rating 6: where, 1) **c**lear zone less than or equal to 1.5 m, 2) sideslope about 1:2, 3) no guardrail, 4) exposed rigid obstacles within 0 to 2 m of the pavement edgeline and 5) non-recoverable, as shown in Figure II.6.

Figure II.6: Typical roadway with roadside hazard rating equal to 6.

Rating 7: where, 1) clear zone less than or equal to 1.5 m, 2) sideslope 1:2 or steeper, 3) cliff or vertical rock cut, 4) no guardrail and 5) non-recoverable with high likelihood of severe injuries from roadside collision, as shown in Figure II.7.

Figure II.7: Typical roadway with roadside hazard rating equal to 7.

Appendix III: Calibration Factor Cr for Highway Segments

Calibration procedure (c_r) to adapt the accident prediction algorithm to the data of a particular highway agency is shown as folloing:

Step 1: Develop estimates of paved rural two-lane highway kilometers by curve and grade.
The State will first need to estimate the following for all paved rural, two-lane highways in the state for each of five ADT groups:

- Number of kilometers of tangent roadway.
- Number of kilometers of roadway on horizontal curves.
- Average degree of curvature for horizontal curves.
- Number of kilometers of level roadway.
- Number of kilometers of roadway on grade.
- Average grade percent for roadway on grade.

For states with alignment (curve and grade) inventory files:
If the State has curve and grade inventory files, then it will be possible to calculate the necessary alignment data to perform the calibration. Using their horizontal curve inventory data, they should first estimate the number of kilometers of tangent roadway, the number of kilometers of curved roadway and the average degree of curve and average length of curve for horizontal curves.
Using their vertical alignment (grade) inventory data files, the state should then calculate the number of kilometers of two-lane rural roads that are not on grade (e.g., level) k1, the number of kilometers with non-zero grades kg, an average percent grade for the kilometers with non-zero grades Pg, and an overall average percent grade (Calculated as $\frac{\mathrm{kg}\times\mathrm{Pg}}{\mathrm{kl}+\mathrm{kg}}$).

For states without alignment (curve and grade) inventory files:
For states without curve or grade files, they can use an estimation procedure that will calculate "default" values for curve and grade kilometers and average degree of curve and percent grade values based on the percent of rural two-lane kilometers that fall into each of the three terrain groups-flat, rolling, and mountainous.

Step 2: Calculate estimate of annual non-intersection accidents using the accident prediction algorithm.
Calculate the predicted annual number of non-intersection related accidents for tangents and curves using the roadway segment accident prediction algorithm. Then, sum the total.

Step 3: Determine actual annual non-intersection accidents from state data.
Using data from the last 3 years, determine the actual number of non-intersection crashes per year that were reported on the rural two-lane highways.

Step 4: Calculate calibration factor using outputs of steps 2 and 3.
Calculate the calibration factor (C_r) as the ratio total number of reported non-intersection accidents on rural two-lane highways (from step 3) to the predicted total number of non-intersection accidents on rural two-lane highways (from step 2).

Example of CPM calibration spreadsheet data - Landkreis Mettmann (2000-2005):

For doing Level 1 calibration for highway segments the State/Agency must have the ability to:
(1) Stratify all two-lane rural roads by ADT; and
(2) Identify all non-intersection related accidents reported on those two lane rural roads.

Instructions for using the spreadsheet:

Follow the instructions below to calculate the CPM calibration factor for highway segments from Level 1 data (Steps described in the text boxes are from the CPM Engineer's Manual and are for information only).

(1) Fill out "Estimated miles of paved, two-lane rural highways" for the five ADT groups in **Table 5** below (Replace the test case numbers that are in **RED**).

(2) Fill out "Proportion of paved, two-lane rural highways (percentage)" in **Table 6** below (Replace the test case numbers that are in **RED**).

(3) If the "Number of Tangent Miles", "Number of Curved Miles", "Average Degree of Curvature for Curved Miles" and "Average Length of Curve" for each ADT group are available, fill-in the corresponding columns in **Table 3** below (auto-generated numbers are in **PINK**). If these data are not available but the "Weighted Average Curve Length" values (see **Table 7)** are available, then fill out Table 7 and push the "Auto Generate" button in **Table 3** (default numbers are in **PINK**). If neither the data for **Table 3** nor **Table 7** are available, then press the "Auto Generate" button in **Table 3** to produce estimates based on data entered in **Tables 5** and **6**, according to the rules documented in the CPM Engineer's Manual.

(4) If the "Number of Level Miles", "Number of Miles on Grade" and "Average Percent Grade for Miles on Grade" for each ADT group are available, fill-in the corresponding columns in **Table 4** below (auto-generated numbers are in **PINK**). If these data are not available, then press the "Auto Generate" button in **Table 4** to produce estimates based on data entered in **Tables 5** and **6**, according to the rules documented in the CPM Engineer's Manual.

(5) Review the values in **Tables 8** and **9**. These are the default/recommended values to be used in the model. If you prefer to use different values, replace the recommended values with your values. (recommended values are in **PINK**).

Note 1: If any of the mileages or ADT Mean Value is 0, enter a very small number (such as 0.01) rather than zero.

Note 2: Pressing the "Auto Generate" buttons in Tables 3, 4, 7, 8, and 9 brings back the default/recommended values in these tables.

(6) Go to **Table 10** and push the "Calculate" button at the bottom of this table. The program will automatically calculate the predicted number of non-intersection-related crashes per year for the five ADT intervals in **Table 9**. The predicted crashes for tangents and curves for each ADT interval are stored in **Table 11**, columns **E** and **F**. The total predicted crashes are shown in column **G**. The total for all ADT ranges is stored in cell **G102**.

(7) In **Table 12,** enter the number of years for which crash data are available in cell **C107,** and the number of actual recorded crashes in cell **E107** (if the number of years is more than 10 the table should be modified).

The value in cell **E119** in **Table 12** is the calculated calibration factor for highway segments (Cr). This represents the ratio of actual recorded crashes to predicted crashes. The calibration factor can be entered into IHSDM via the **AdminTool**.

Step 1. Develop Estimates of Paved Rural Two-Lane Highway Mileage by Curve and Grade.

The State will first need to estimate the following for all paved rural, two-lane highways in the State for each of **five ADT** groups:

- Number of miles of tangent roadway.
- Number of miles of roadway on horizontal curves.
- Average degree of curvature for horizontal curves.
- Number of miles of level roadway.
- Number of miles of roadway on grade.
- Average grade percent for roadway on grade

Total Mileage	91.362	
	Step 1, A: For States with Alignment (Curve and Grade) Inventory Files	

Table 1. Horizontal Alignment Defaults from HSIS Data

	% of Non-tangent Miles	Avg. Degree of Curve
Flat	19	2
Rolling	24	4
Mountanous	38	8

Table 2. Vertical Alignment Defaults from HSIS Data

	% of Non-flat Miles	Avg. Grade %
Flat	87	1.5
Rolling	91	2.0
Mountanous	97	3.7

Table 3. Estimate Mileage by ADT Level and Horizontal Alignment

ADT Interval	Number of Tangent Miles	Number of Curved Miles	Average Degree of Curvature for Curved Miles (D)	Average Radius of Horizontal Curve[a]	Average Length of Curve (mi)
< 1000	0.000	0.000	0.000	0.000	0.000
1,001 - 3,000	3.815	6.889	45.749	202.000	0.101
3,001 - 5,000	5.642	7.868	28.807	320.800	0.119
5,001 - 10,000	17.991	27.480	24.513	377.000	0.154
> 10,000	14.145	14.589	19.414	476.000	0.226
	41.59	**56.83**			

Table 4. Estimate Mileage by ADT Level and Vertical Alignment

ADT Interval	Number of Level Miles (Ml)	Number of Miles on Grade (Mg)	Average Percent Grade for Miles on Grade (Pg)	Average Percent Grade[a]
< 1000	0.000	0.000	0.000	0.000
1,001 - 3,000	9.865	0.964	3.500	0.312
3,001 - 5,000	8.826	3.010	3.000	0.763
5,001 - 10,000	41.773	7.207	4.000	0.589
> 10,000	24.367	4.600	2.750	0.437
	84.83	15.78		

Step 1, B: For States without Alignment (Curve and Grade) Inventory Files

Table 5. Estimate Mileage by ADT Interval

ADT Interval	Estimated miles of paved, two-lane rural highways
< 1000	0.000
1001 - 3000	10.829
3001 - 5000	13.538
5001 - 10000	39.975
> 10000	27.020
	91.362

Table 6. Estimate Proportion of Mileage by Terrain

Terrain	Proportion of paved, two-lane rural highways (percentage)
Flat	100.000
Rolling	0.000
Mountainous	0.000
Total	100

Table 7. Weighted Average Curve Length from MI and WA Data

Calculated Average Length of Curve for the following Average Degree of curve

	Degree of Curve	Weighted Average Curve Length				
		Miles	Feet	Miles	Feet	
< 1000	2	0.184	974	0.0000	0	**0.00**
	4	0.120	636	0.0000	0	
	8	0.081	427	0.0000	0	

1001 - 3000	2	0.184	974	0.0000	0	**45.75**
	4	0.120	636	0.0000	0	
	8	0.081	427	0.0000	0	
3001 - 5000	2	0.184	974	0.0000	0	**28.81**
	4	0.120	636	0.0000	0	
	8	0.081	427	0.0000	0	
5001 - 10000	2	0.184	974	0.0000	0	**24.51**
	4	0.120	636	0.0000	0	
	8	0.081	427	0.0000	0	
> 1000	2	0.184	974	0.0000	0	**19.41**
	4	0.120	636	0.0000	0	
	8	0.081	427	0.0000	0	

Step 2.Accept or Modify Default Values for Other Geometric Parameters

Table 8. Default Values

Shoulder type (Paved/Gravel/Turf)	Paved
Roadside Hazard Rating (RHR)	3
Driveway density (driveways/mi)	5
Presence of spiral transition curve(0/1/2)	0
Superelevation AMF (AMF4)	1
Passing lane (Yes/No)	No
Short four-lane section (Yes/No)	No
Two Way Left Turn Lane	No

Table 9. Default Values

ADT Interval (Vehicles/day)	**ADT (vehicles/day)**	**Lane Width (ft)**	**Shoulder Width (ft)**
< 1000	400.000	10.000	0.000
1,001 - 3,000	2500.000	10.000	0.000
3,001 - 5,000	4300.000	11.500	0.000
5,001 - 10,000	75000.000	12.000	0.000
> 10,000	14500.000	12.500	0.000

Step 3. Calculate Estimate of Annual Non-Intersection Accidents Using the Accident Prediction Algorithm

Table 10. Effective values for single ADT Groups and calculated presicted number of crashes

ADT Group	**5**	**Mileage for Tangents**	**Mileage for Curves**	**Prediction from Level1-Tangents**	**Prediction from Level1-Curves**
ADT	14500	14.145	14.589	54.5	83.2
Lane Width	12.5				
Shoulder Width	0				
Length of horizontal curve (mi)	0.226000				
Radius of horizontal curve (ft)	476				
Percent Grade	0.44				

Table 11. Final values for ADT Groups and calculated presicted number of crashes

ADT Interval	**Mileage of rural two lane highways**	**Predicted number of non-intersection accident per year****

(Vehicles/day)	Tangent	Curve	Total	Tangent	Curve	Total
< 1000	0	0	0	690.1	292.0	982
1,001 - 3,000	3.815	6.889	10.704	1163.0	492.0	1655
3,001 - 5,000	5.642	7.868	13.51	697.1	294.9	992
5,001 - 10,000	17.991	27.48	45.471	909.3	384.7	1294
> 10,000	14.145	14.589	28.734	587.8	248.7	836
				4047	1712	577

Step 4. Determine Actual Annual Non-Intersection Accidents from State Data for the Last Three Years

Table 12. Calibration Factor calculation

	Recorded crashes for years	**6**	**years**	**2767**		
	Year 1 predicted crashes			577		
	Year 2 predicted crashes			577		
	Year 3 predicted crashes			577		
	Year 4 predicted crashes			577		
	Year 5 predicted crashes			577		
	Year 6 predicted crashes			577		
	Year 7 predicted crashes			0		
	Year 8 predicted crashes			0		
	Year 9 predicted crashes			0		
	Year 10 predicted crashes			0		
	Total			3462		
Ratio (Calculated Calibration Factor Cr for segments)				**0.80**		

Apendix IV: Accident Modification Factors (AMFs)

The AMFs for highway segments include all of the variables in the highway segment base model.

1) Lane width (AMF_1)

The value of the AMF for lane width (AMF_{ra}) is determined as shown in Table IV-1. If the lane width is less than or equal to 3 m, the AMF for 3 m shown in the table is used. If the lane width is greater than or equal to 3.75 m, the AMF for 3.75 m is used. If the lane width is equal to 3, 3.25, 3.5, or 3.75 m, the value of the AMF is shown or is computed with the formulas provided in the table. If the lane width falls between the integers values listed, the value of AMFra is determined by interpolation between the values for those integer values of lane width.

Table IV-1: Values of AMF_1 for lane width of highway segments (AMF_{ra})

Lane width (m)	ADT < = 400	ADT > 401
3.00	1.16	1.67
3.25	1.09	1.39
3.50	1.06	1.10
3.75	1.00	1.00

The value of AMF_{ra} is modified as follows to convert it from related accidents to total accidents:

$$AMF_1 = (AMF_{ra} - 1.0)P_{ra} + 1.0 \qquad \text{(IV-1)}$$

Where, AMF_1 is accident modification factor for total accidents, AMF_{ra} is accident modification factor for related accidents, and P_{ra} is proportion of total accidents constituted by related accidents The proportion of related accidents (P_{ra}) should be set equal to the sum of four values from expressed as a proportion rather than as a percentage. These four values are:

- Percentage of single vehicle run-off-road accidents.
- Percentage of multiple-vehicle head-on collisions.
- Percentage of multiple-vehicle opposite-direction sideswipe collisions.
- Percentage of multiple-vehicle same-direction sideswipe collisions.

2) Shoulder width and type (AMF_2)

For each side of the highway shoulder, effective width is defined as 2.5 m if the width of the shoulder on that side of the highway is greater or equal to 2.5 m, and is the actual shoulder width if it is less than 2.5 m wide.

The AMF_2 for shoulder width (AMF_{wra}) is determined as shown in Table IV-2. If the shoulder effective width is equal to 0, 1, 1.5, 2, or 2.5 m, the value of AMF_{wra} is shown or is computed with the formulas provided in the table. If the shoulder effective width falls between these values, the value of AMF_{wra} is determined by interpolation.

If there is only one type of shoulder on the same side of the highway, the AMF for shoulder type (AMF_{tra}) for that side of the highway is determined from Table IV-3. If there are more than one type of shoulder on the same side of the highway, only the shoulder types within the effective width of the shoulder would be considered in the calculation of the AMF for shoulder type (AMF_{tra}) for that side of the highway. In this case, AMF_{tra} for each type of shoulder within the effective width is determined from Table IV-3. Then, a weighted average of the calculated AMF_{tra} is taken, with the actual width of each type divided by the effective width as the weight for each type. The AMF for shoulder width and type combined is determined as follows:

$$AMF_2 = (AMF_{wra} \times AMF_{tra} - 1.0)P_{ra} + 1.0 \qquad \text{(IV-2)}$$

Where, AMF_{wra} is accident modification factor for related accidents based on shoulder width and AMF_{tra} is accident modification factor for related accidents based on shoulder type.

Table IV-2: Values of AMF for shoulder width of highway segments (AMF_{wra})

Shoulder effective width (m)	ADT <=400	ADT > 401
0	1.10	1.50
1.0	1.07	1.30
1.5	1.02	1.15
2.0	1.00	1.00
2.5	0.98	0.87

Table IV-3: Accident modification factors for shoulder effective width (SEW) and shoulder type on two-lane highways (AMF_{tra})

Shoulder type	SW=0 m	SW=1.0 m	SW=1.5 m	SW=2.0 m	SW=2.5 m
Paved	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.01	1.01	1.02	1.02
Turf	1.00	1.03	1.05	1.08	1.11

The proportion of related accidents (P_{ra}) used in equation (IV-2) should be the same as that used in equation (IV-1). If the shoulder effective width and/or shoulder types differ between the two directions of travel for any highway segment, AMF_2 is computed separately for each direction of travel and the results averaged.

3) **Horizontal curve length, radius, and presence or absence of spiral transition (AMF_3).**

If a highway segment is located on a tangent highway or on a spiral transition curve (i.e., not on a circular horizontal curve), then the value of AMF_3 is 1.00.

If a highway segment is located on a horizontal curve, then the value of AMF_3 is determined as follows:

$$AMF_3 = \frac{2.49\,L_c + \frac{264.66}{R} - - 0.012\,S}{2.49\,L_c} \qquad \text{(IV-3)}$$

Where, L_c is length of horizontal curve (km), R is radius of curvature (m) and S is 1 if spiral transition curve is present, 0 if spiral transition curve is not present; 0.5 if spiral transition curve is present on one end of circular curve

Some highway segments may be shorter than the horizontal curve being analyzed; L_c represents the total length of the horizontal curve which may be greater than the length of the highway segment. Where spiral transitions are present, L_c represents the length of the circular curve plus the lengths of spiral transitions.

AMFs are computed for each curve in a compound curve set. The length of the horizontal curve (L_c) used in equation IV-3 is the total length for the compound curve set and the radius of curvature (R) is the radius for the individual curve in the compound curve set that is being analyzed.

If the computed value of AMF_3 for a horizontal curve is less than 1.00, AMF_3 is set equal to 1.00. This AMF applies to total highway segment accidents.

4) **Superelevation (AMF_4)**

The AMF for the superelevation of a horizontal curve is based on the superelevation deficiency defined as the difference between the actual superelevation of the horizontal curve (e_{act}) and the design superelevation (e_{design}) specified in the 1994 AASHTO Green Book. Superelevation deficiency (SD) is computed as:

$$SD = 0.00 \qquad \text{if } e_{act} > e_{design} \qquad \text{(IV-4)}$$

$$SD = e_{design} - e_{act} \qquad \text{if } e_{act} < e_{design} \qquad \text{(IV-5)}$$

The value of e_{act} for each horizontal curve is that input by the user as part of the highway geometric data. In applying equation IV-6, negative values of e_{act} are permitted; such negative values are associated with superelevation with the opposite cross slope to that intended, which may well be associated with a superelevation deficiency. The value of e_{design} is determined from interpolation in Design Superelevation tables (see Table IV-4 to Table IV-8). Use of the Design Superelevation tables requires the horizontal curve radius, the horizontal curve design speed, and the value of the maximum superelevation rate (e_{max}) used by a highway agency. Interpolation of values of e_{design} between the radii shown in the Design Superelevation tables for a given value of e_{max} is performed. If e_{design} exceeds 0.120, e_{design} is set equal to 0.120.

The value of the AMF for superelevation (AMF_4) is determined as:

$$AMF_4 = 1.00 \quad \text{for} \quad SD \leq 0.01 \tag{IV-6}$$

$$AMF_4 = 1.00 + 6\,(SD-0.01) \quad \text{for} \quad 0.01 < SD < 0.02 \tag{IV-7}$$

$$AMF_4 = 1.06 + 3\,(SD-0.03) \quad \text{for} \quad SD \geq 0.02 \tag{IV-8}$$

Table IV-4: Design superelevation (e_{design}) as a function of maximum superelevation rate (e_{max} =0.04), horizontal curve radius and design speed (V km/h)

e_{max}	**Radius (m)**	**V=50 (km/h)**	**V=65 (km/h)**	**V=80 (km/h)**	**V=100 (km/h)**	**V=120 (km/h)**
0.04	6945	0.000	0.000	0.000	0.000	0.000
0.04	3472	0.000	0.000	0.000	0.000	0.000
0.04	2315	0.000	0.000	0.000	0.000	0.000
0.04	1736	0.000	0.000	0.000	0.025	0.025
0.04	1058	0.000	0.000	0.024	0.029	0.029
0.04	868	0.000	0.022	0.027	0.033	0.033
0.04	695	0.000	0.025	0.030	0.036	0.036
0.04	579	0.020	0.027	0.033	0.039	0.039
0.04	496	0.022	0.028	0.035	0.040	0.040
0.04	434	0.024	0.030	0.037	0.040	0.040
0.04	347	0.026	0.033	0.039	0.040	0.040
0.04	289	0.028	0.036	0.040	0.040	0.040
0.04	289	0.030	0.037	0.040	0.040	0.040
0.04	248	0.031	0.039	0.040	0.040	0.040
0.04	217	0.033	0.040	0.040	0.040	0.040
0.04	193	0.034	0.040	0.040	0.040	0.040
0.04	174	0.035	0.040	0.040	0.040	0.040
0.04	158	0.036	0.040	0.040	0.040	0.040
0.04	145	0.037	0.040	0.040	0.040	0.040
0.04	134	0.038	0.040	0.040	0.040	0.040
0.04	124	0.039	0.040	0.040	0.040	0.040
0.04	109	0.040	0.040	0.040	0.040	0.040
0.04	96	0.040	0.040	0.040	0.040	0.040
0.04	87	0.040	0.040	0.040	0.040	0.040
0.04	79	0.040	0.040	0.040	0.040	0.040
0.04	72	0.040	0.040	0.040	0.040	0.040

Table IV-5: Design superelevation (e_{design}) as a function of maximum superelevation rate (e_{max} =0.06), horizontal curve radius and design speed (V km/h)

e_{max}	**Radius (m)**	**V=50 (km/h)**	**V=65 (km/h)**	**V=80 (km/h)**	**V=100 (km/h)**	**V=120 (km/h)**
0.06	6945	0.000	0.000	0.000	0.000	0.000
0.06	3472	0.000	0.000	0.000	0.000	0.000
0.06	2315	0.000	0.000	0.000	0.021	0.026
0.06	1736	0.000	0.000	0.020	0.027	0.033
0.06	1058	0.000	0.020	0.025	0.037	0.046
0.06	868	0.000	0.025	0.030	0.045	0.055
0.06	695	0.020	0.030	0.034	0.051	0.059
0.06	579	0.023	0.034	0.038	0.055	0.060
0.06	496	0.026	0.038	0.041	0.058	0.060
0.06	434	0.029	0.041	0.046	0.060	0.060
0.06	347	0.034	0.046	0.050	0.060	0.060
0.06	289	0.038	0.050	0.053	0.060	0.060
0.06	289	0.041	0.053	0.056	0.060	0.060
0.06	248	0.043	0.056	0.058	0.060	0.060
0.06	217	0.046	0.058	0.059	0.060	0.060

0.06	193	0.048	0.059	0.060	0.060	0.060
0.06	174	0.050	0.060	0.060	0.060	0.060
0.06	158	0.052	0.060	0.060	0.060	0.060
0.06	145	0.054	0.060	0.060	0.060	0.060
0.06	134	0.055	0.060	0.060	0.060	0.060
0.06	124	0.058	0.060	0.060	0.060	0.060
0.06	109	0.059	0.060	0.060	0.060	0.060
0.06	96	0.060	0.060	0.060	0.060	0.060
0.06	87	0.060	0.060	0.060	0.060	0.060
0.06	79	0.060	0.060	0.060	0.060	0.060
0.06	72	0.060	0.060	0.060	0.060	0.060

Table IV-6: Design superelevation (e_{design}) as a function of maximum superelevation rate (e_{max} =0.08), horizontal curve radius and design speed (V km/h).

e_{max}	Radius (m)	V=50 (km/h)	V=65 (km/h)	V=80 (km/h)	V=100 (km/h)	V=120 (km/h)
0.08	6945	0.000	0.000	0.000	0.000	0.000
0.08	3472	0.000	0.000	0.000	0.000	0.000
0.08	2315	0.000	0.000	0.000	0.022	0.028
0.08	1736	0.000	0.000	0.021	0.029	0.036
0.08	1058	0.000	0.021	0.030	0.041	0.051
0.08	868	0.000	0.027	0.038	0.051	0.065
0.08	695	0.021	0.033	0.046	0.061	0.075
0.08	579	0.025	0.038	0.053	0.068	0.080
0.08	496	0.028	0.043	0.058	0.074	0.080
0.08	434	0.031	0.047	0.063	0.078	0.080
0.08	347	0.038	0.055	0.071	0.080	0.080
0.08	289	0.043	0.062	0.077	0.080	0.080
0.08	289	0.048	0.067	0.080	0.080	0.080
0.08	248	0.053	0.071	0.080	0.080	0.080
0.08	217	0.056	0.075	0.080	0.080	0.080
0.08	193	0.060	0.078	0.080	0.080	0.080
0.08	174	0.063	0.079	0.080	0.080	0.080
0.08	158	0.065	0.080	0.080	0.080	0.080
0.08	145	0.068	0.080	0.080	0.080	0.080
0.08	134	0.070	0.080	0.080	0.080	0.080
0.08	124	0.074	0.080	0.080	0.080	0.080
0.08	109	0.077	0.080	0.080	0.080	0.080
0.08	96	0.079	0.080	0.080	0.080	0.080
0.08	87	0.080	0.080	0.080	0.080	0.080
0.08	79	0.080	0.080	0.080	0.080	0.080
0.08	72	0.080	0.080	0.080	0.080	0.080

Table IV-7: Design superelevation (e_{design}) as a function of maximum superelevation rate (e_{max} =0.10), horizontal curve radius and design speed (V km/h)

e_{max}	Radius (m)	V=50 km/h)	V=65 (km/h)	V=80 (km/h)	V=100 (km/h)	V=120 (km/h)
0.10	6945	0.000	0.000	0.000	0.000	0.000
0.10	3472	0.000	0.000	0.000	0.000	0.000
0.10	2315	0.000	0.000	0.000	0.023	0.028
0.10	1736	0.000	0.000	0.021	0.030	0.037
0.10	1058	0.000	0.021	0.031	0.043	0.054
0.10	868	0.000	0.028	0.040	0.055	0.070
0.10	695	0.021	0.034	0.049	0.067	0.085
0.10	579	0.025	0.040	0.057	0.077	0.096
0.10	496	0.029	0.046	0.065	0.086	0.100
0.10	434	0.033	0.051	0.072	0.093	0.100

0.10	347	0.040	0.061	0.083	0.098	0.100
0.10	289	0.046	0.070	0.092	0.100	0.100
0.10	289	0.053	0.078	0.098	0.100	0.100
0.10	248	0.058	0.084	0.100	0.100	0.100
0.10	217	0.063	0.089	0.100	0.100	0.100
0.10	193	0.068	0.094	0.100	0.100	0.100
0.10	174	0.072	0.097	0.100	0.100	0.100
0.10	158	0.076	0.099	0.100	0.100	0.100
0.10	145	0.080	0.100	0.100	0.100	0.100
0.10	134	0.083	0.100	0.100	0.100	0.100
0.10	124	0.089	0.100	0.100	0.100	0.100
0.10	109	0.093	0.100	0.100	0.100	0.100
0.10	96	0.097	0.100	0.100	0.100	0.100
0.10	87	0.099	0.100	0.100	0.100	0.100
0.10	79	0.100	0.100	0.100	0.100	0.100

Table IV-8: Design superelevation (e_{design}) as a function of maximum superelevation rate (e_{max} =0.12), horizontal curve radius and design speed (V km/h)

e_{max}	Radius (m)	V=50 km/h)	V=65 (km/h)	V=80 (km/h)	V=100 (km/h)	V=120 (km/h)
0.12	6945	0.000	0.000	0.000	0.000	0.000
0.12	3472	0.000	0.000	0.000	0.000	0.000
0.12	2315	0.000	0.000	0.000	0.023	0.029
0.12	1736	0.000	0.000	0.022	0.030	0.038
0.12	1058	0.000	0.022	0.032	0.044	0.056
0.12	868	0.000	0.029	0.042	0.058	0.073
0.12	695	0.022	0.035	0.051	0.070	0.090
0.12	579	0.026	0.042	0.060	0.082	0.106
0.12	496	0.030	0.048	0.069	0.094	0.118
0.12	434	0.034	0.054	0.077	0.104	0.120
0.12	347	0.041	0.065	0.092	0.117	0.120
0.12	289	0.049	0.075	0.104	0.120	0.120
0.12	289	0.055	0.085	0.113	0.120	0.120
0.12	248	0.068	0.094	0.119	0.120	0.120
0.12	217	0.068	0.101	0.120	0.120	0.120
0.12	193	0.074	0.107	0.120	0.120	0.120
0.12	174	0.079	0.112	0.120	0.120	0.120
0.12	158	0.084	0.116	0.120	0.120	0.120
0.12	145	0.089	0.119	0.120	0.120	0.120
0.12	134	0.093	0.120	0.120	0.120	0.120
0.12	124	0.101	0.120	0.120	0.120	0.120
0.12	109	0.108	0.120	0.120	0.120	0.120
0.12	96	0.113	0.120	0.120	0.120	0.120
0.12	87	0.116	0.120	0.120	0.120	0.120
0.12	79	0.119	0.120	0.120	0.120	0.120
0.12	72	0.120	0.120	0.120	0.120	0.120

5) Grades (AMF_5)

The AMF for percent grade (AMF_5) is determined as:

$$AMF_5 = (1.016)^{|PG|} \qquad \text{(IV-9)}$$

Where, PG is percent grade for the highway segment

If the percent grade exceeds 12 percent, PG is set equal to 12 percent. Grades are determined from Vertical Point of Intersection (VPI) to Vertical Point of Intersection. Vertical curves are not considered.

6) Driveway density (AMF_6)

The AMF for driveway density (AMF_6) is determined as:

$$\mathrm{AMF_6} = \frac{0.2+(0.05-0.005\ln \mathrm{ADT_y})\times \mathrm{DD}}{0.2+(0.05-0.005\ln \mathrm{ADT_y})\times 5} \qquad \text{(IV-10)}$$

Where, $\mathrm{ADT_y}$ is annual average daily traffic volume of the highway being evaluated (veh/day) and DD is driveway density for both sides of the road combined (driveways/km)

7) **Passing lanes and short four-lane sections ($\mathrm{AMF_7}$)**

If no passing lane is present on a highway segment, then the value of $\mathrm{AMF_7}$ is 1.00.

If a passing lane is present in one direction of travel (i.e., two lanes in one direction and one lane in the other direction of travel), then the value of $\mathrm{AMF_7}$ is 0.75.

If a short four-lane section is provided on a two-lane highway, then the value of $\mathrm{AMF_7}$ is 0.65. The value of 0.65 should be used for any cross section where two lanes are provided in both directions of travel; this value should be used for short four-lane sections that begin and end at the same station or for any area where passing lanes in opposing directions of travel overlap.

8) **Two-Way left-turn lanes ($\mathrm{AMF_8}$)**

If no center TWLTL is present on a highway section, the value of $\mathrm{AMF_8}$ is 1.00.

If a center TWLTL is present, the value of the AMF is determined as:

$$\mathrm{AMF_8} = 1.00 - 0.35\mathrm{P_{AP}} \qquad \text{(IV-11)}$$

Where, $\mathrm{P_{AP}}$ is access-point-related accidents as a proportion of total accidents

The value of $\mathrm{P_{AP}}$ is determined as:

$$\mathrm{P_{AP}} = \frac{0.0047\mathrm{DD}+0.0024\mathrm{DD}^2}{1.199+0.0047\mathrm{DD}+0.0024\mathrm{DD}^2} \qquad \text{(IV-12)}$$

If the driveway density (DD) is less than three driveways per km, the value of $\mathrm{AMF_8}$ is 1.00.

9) **Roadside hazard rating ($\mathrm{AMF_9}$)**

The AMF for roadside hazard rating (AMF9) is determined as:

$$\mathrm{AMF_9} = \frac{e^{-0.6869+0.0668\mathrm{RHR}}}{e^{-0.4865}} \qquad \text{(IV-13)}$$

Where, RHR is roadside hazard rating for the highway segment considering both sides of the road (1 to 7 scale).

The roadside hazard rating for a highway section ranges from 1 (best roadside) to 7 (poorest roadside). This roadside hazard rating scale is explained and illustrated in Appendix II.

Appendix V: Methodical Procedure for DCM

The safety procedure presented consists of 8 hierarchical steps for two-lane rural roads.

1. Assess the road section to determine where safety examinations of the existing alignment should be conducted.
2. Determine the kind of design elements (circular curves, clothoids, tangents) present in the roadway section, the corresponding geometric parameters (R, A), and length (L), as well as the superelevation rates (e) at curved sited.
3. Differentiate between curves and tangents and between independent tangents and nonindependent tangents according to the limiting ranges in Table V-1 or Table V-2. Only independent tangents are considered.
4. Calculate the curvature change rate of the single curve with transition curves, CCRs, it is calculated using eq. V-1. For independent tangents, CCRs =0 gon/km.

$$\mathrm{CCRs} = \left(\frac{\mathrm{L_{cl1}}}{2\mathrm{R}} + \frac{\mathrm{L_{cr}}}{\mathrm{R}} + \frac{\mathrm{L_{cl2}}}{2\mathrm{R}}\right) \times \frac{63{,}700}{\mathrm{L}} \qquad \text{(V-1)}$$

Where, CCRs iscurvature change rate of the single curve with transition curves, gon/km; L is the length of curve = L_{cr} +L_{cl1}+L_{cl2} , km; L_{cr} is length of circular curve, m; R is radius of circular curve, m; L_{cl1}, L_{cl2} are lengths of clothoids, m and 63,700 = 200/ π * 1000

5. Determine the 85th percentile speed, V_{85}, for each curved site and independent tangents with respect to the design parameter CCRs, it is determining by using eq. V-2.

$$\mathrm{V_{85}} = \frac{10^6}{8270 + 8.01 \times \mathrm{CCRs}} \qquad \text{(V-2)}$$

6. Assess the design speed, V_d, for the examined roadway section. Note that, for existing alignments, the design speed is often not known. A sound design speed can be estimated in the following way: Calculate the length-related average $\overline{CCRs}$ value based on all the curves in the observed roadway section according to eq. V-3. Tangent sections should not be included. Determine for this average $\overline{CCRs}$ value the corresponding average 85th percentile speed, $V_{85\ av}$, by using eq. V-2 . This average 85th percentile speed represents a good estimate for the assumed design speed, V_d.

$$\overline{CCRs} = \frac{\sum_{i=1}^{i=n} CCRs_i \times L_i}{\sum_{i=1}^{i=n} L_i} \qquad \text{(V-3)}$$

7. Evaluate safety criterion I: Calculate the difference between V_{85}, and V_d according to the classification system in Table 5-1 for good, fair (tolerable), and poor design levels for each individual design element.
8. Evaluate safety criterion II: Calculate the difference between V_{85}, between successive design segments (independent tangent i to i+1 or curve i to curve i+1) according to the classification system in Table 5-1 for good, fair (tolerable), and poor design levels for each individual design element.
9. Analyze the results of safety criteria I and II with respect to good, fair, and poor design practices throughout the length of the existing alignment being examined.

Table V-1: Relationship between tangent lengths and 85th percentile speed change for sequences: tangent-to-curve ($V_{85}T < 105$ km/h).

V_{85} in curve, km/h	**$V_{85}T$ in Tangent, km/h**						
	70	**75**	**80**	**85**	**90**	**95**	**100**
50	110	140	175	215	255	295	340
55	-	120	155	190	230	270	315
60	-	-	125	165	205	245	290
65	-	-	-	135	175	220	260
70	-	-	-	-	145	185	235
75	-	-	-	-	-	155	200
80	-	-	-	-	-	-	165

☐ Short tangent lengths TLS; m, the maximum allowable lengths of tangents regarded as nonindependent design elements.

Table V-2: Relationship between tangent lengths and 85^{th} percentile speed change for sequences: tangent-to-curve ($V_{85}T \geq 105$ km/h).

V85 in curve, km/h	**$V_{85}T$ in Tangent, km/h**						
	90	95	100	105	110	115	120
70	145	185	230	280	325	380	430
75	-	155	200	245	295	345	400
80	-	-	165	210	260	310	365
85	-	-	-	170	220	270	325
90	-	-	-	-	180	235	285
95	-	-	-	-	-	190	245
100	-	-	-	-	-	-	200

Appendix VI: IHSDM Evaluation Report

Policy Review Evaluation Report

IHSDM Version: 5.0.2 IHSDM 2008 Release

Report Date: Oct 31, 2009 5:02:09 AM

Name: nagham Mehaibes

Project: Project 1 (May 31, 2009 1:57 AM)

Evaluation: PRM (5:01 AM)

Highway Information: Wuelfraeth City 2 (v1)

Policy Review Module Version: 2.5.11 (Sep 18, 2008)

Policy: AASHTO 2004 Metric

Processing Limits: 0.000 to 8+235.000

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Traveled Way Width Policy Check

Table 1: Traveled way width and widening- sample (3 sections).

Stations		Traveled Way Width and Widening		Comment	Attributes
Start	End	Road (width+widening) (m)	Policy (width+widening) (m)		
0.000	207.000	8.50 + 0.00	7.20 + 0.00	Road value is within controlling criteria	design speed=80 (km/h); class=arterial; terrain=level; ADT=8,844 (v/day)
1+693.000	1+853.000	7.40 + 0.00	7.20 + 1.30	Road value varies from controlling criteria	design speed=80 (km/h); class=arterial; terrain=level; ADT=14,739 (v/day); radius=190.00 (m); Policy TWW=7.20 m
1+853.000	1+973.000	7.40 + 0.00	7.20 + ???	No policy values in AASHTO 2004 Metric: minimum curve widening	design speed=80 (km/h); class=arterial; terrain=level; ADT=14,739 (v/day); radius=140.00 (m); Policy TWW=7.20 m

Radius of Curve Policy Check

Table 2: Radius of curve- sample (2 sections).

Stations		Radius of Curve		Effective Design Speed (km/h)	Comment	Attributes
Start	End	Road (m)	Policy (m)			
207.000	322.000	320.00	229.00	90	Road value is within controlling criteria	Emax=8.00 (%); design speed=80 (km/h)
1+408.000	1+533.000	200.00	229.00	75	Road value varies from controlling criteria	Emax=8.00 (%); design speed=80 (km/h)

Table 3: eMax bounds.

Stations		eMax Bounds		Comment	Attributes
Start	End	Road (%)	Policy (%)		
0.000	8+235.000	8.00	4.00 to 12.00	Road value is within controlling criteria	class=arterial; surface type=paved

Tangent Grade Policy Check

Table 4: Tangent grade- sample (2 sections).

Stations		Tangent Grade		Comment	Attributes
Start	End	Road (%)	Policy (%)		
0.000	1+603.000	3.00	0.30 to 4.00	Road value is within controlling criteria	class=arterial; design speed=80 (km/h); length=1,603.00 (m)
5+930.000	6+930.000	7.00	0.30 to 4.00	Road value varies from controlling criteria	class=arterial; design speed=80 (km/h); length=1,000.00 (m)

Stopping Sight Distance Policy Check

Policy Table Bounds:

20 (km/h) to 130 (km/h), Object Height: 600.0 (mm), Driver Eye Height: 1,080.0 (mm), Driver Increment: 2.00 (m).

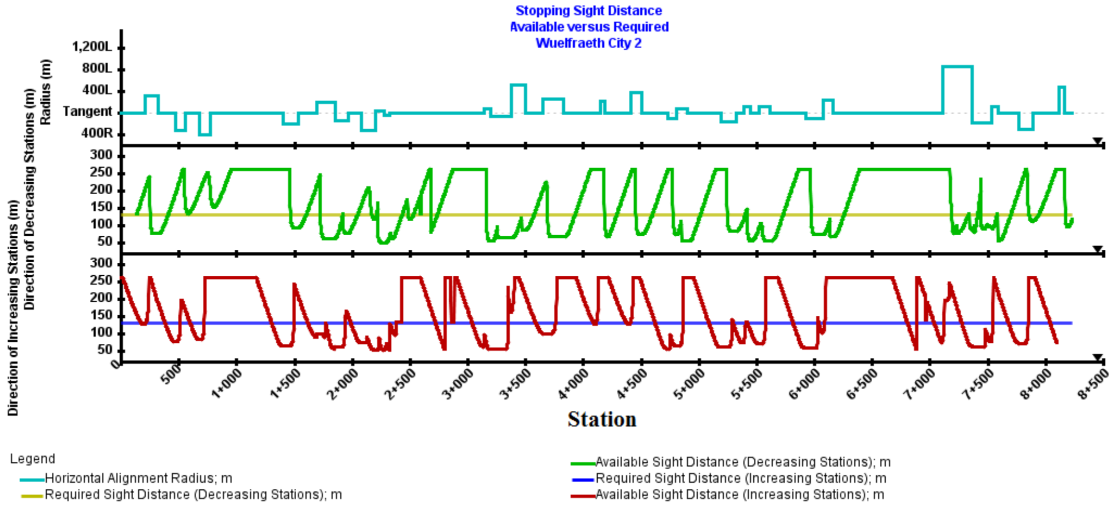

Figure 1: Stopping sight distance.

Table 5: Stopping sight distance- sample (2 sections).

Stations		Direction of Travel	Stopping Sight Distance		Comment	Attributes
Start	End		Road (min.) m	Policy m		
0.000	182.000	Increasing Stations		130.00	Road value is within controlling criteria	design speed=80 (km/h)
184.000	214.000	Increasing Stations	126.00	130.00	Road value may vary from recommended values, Obstruction Offset is closer than edge of pavement, check obstructions beyond pavement; source of SD limitation is horizontal alignment	design speed=80 (km/h)

Passing Sight Distance Policy Check

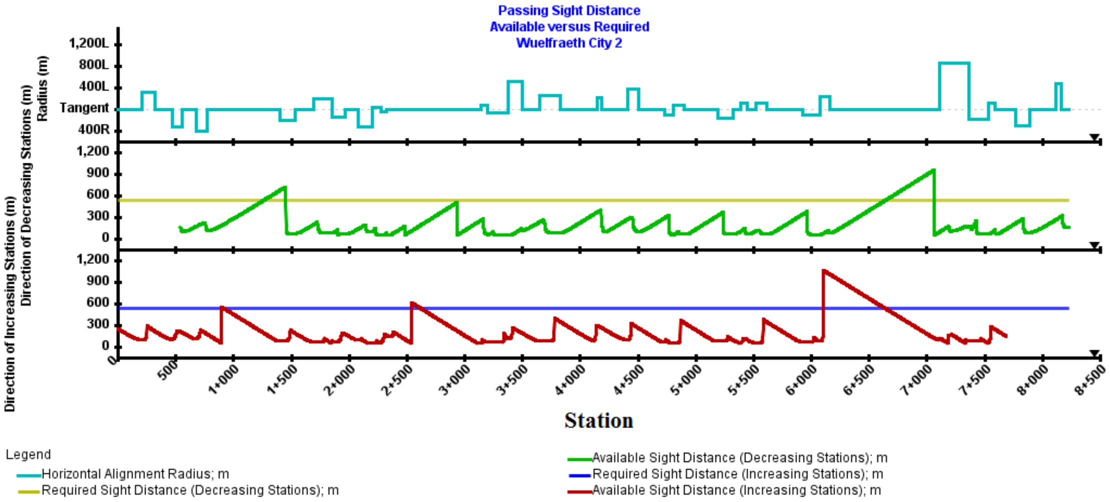

Figure 2: Passing sight distance.

Table 6: Passing sight distance- sample (2 sections).

Stations		Direction of Travel	Passing Sight Distance		Comment	Attributes
Start	End		Road (min.) m	Policy m		
0.000	900.000	Increasing Stations	50.00	540.00	Road value may vary from recommended values, Obstruction Offset is closer than edge of pavement, check obstructions beyond pavement; source of SD limitation is horizontal alignment	design speed=80 (km/h)
902.000	912.000	Increasing Stations		540.00	Road value is within recommended values	design speed=80 (km/h)

Decision Sight Distance Policy Check

Table 7: Decision sight distance- sample (2 sections).

Stations		Direction of Travel	Passing Sight Distance		Comment	Attributes
Object	Eye		Road m	Policy m		
953.000	812.000	Increasing Stations	> 280.00	140.00	Road value is within recommended values	design speed=80 (km/h); maneuver=A
3+143.000	3+188.000	Decreasing Stations	45.00	140.00	Road value may vary from recommended values, Obstruction Offset is closer than edge of pavement, check obstructions beyond pavement; source of SD limitation is horizontal alignment	design speed=80 (km/h); maneuver=A

Crash Prediction Evaluation Report- WITHOUT HISTORY

IHSDM Version: 5.0.2 IHSDM 2008 Release

Report Date: Oct 31, 2009 5:03:10 AM

Name: nagham Mehaibes

Project: Project 1 (May 31, 2009 1:57 AM)

Evaluation: CPM (WITHOUT HISTORY) (5:02 AM)

Highway Information: Wuelfraeth City 2 (v1)

Crash Prediction Module Version: 1.4.7 (Nov 20, 2008)

Evaluation Length: 8.2350 kilometers

Crash History Data: None

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Highway Segment Summary

Table 1: Proposed highway segment data- sample (2 sections).

Seg #	Station		Length (m)	Lane Width		Shoulder Width		Shoulder Type		Driveway Density dwys/km	Roadside Hazard Rating	Horiz. Curve Number	Grade (%)	Passing Lane		Center TWLTL
	Start	End		R	L	R	L	R	L					R	L	
1	0	207	207	4.25	4.25	0.0	0.0	N/A	N/A	1.0	5.0	-	3.00	no	no	no
2	207	322	115	4.25	4.25	0.0	0.0	N/A	N/A	1.0	5.0	1	3.00	no	no	no

Horizontal Curve Summary

Table 2: Proposed horizontal curve data- sample (2 sections).

Horizontal Curve Number	Station		Length of Curve (m)	Radius (m)	Superelevation (%)	Design Speed (km/h)	Spiral Transition
	Start	End					
1	207	322	115	320	Left 2.0 adverse Right 2.0	80	none
2	472	562	90	325	Left 2.0 Right 2.0 adverse	80	none

Proposed Segment Traffic Volume

Table 3: Proposed segment traffic volume.

Segment #	Station		Evaluation Period ADT (veh/day)					
	Start	End	2010	2011	2012	2013	2014	2015
1 to 7	0	953	8,844	8,844	8,844	8,844	8,844	8,844
8 to 63	953	8+235	14,739	14,739	14,739	14,739	14,739	14,739

Expected Crash Rates and Frequencies

Table 4: Expected crash rates and frequencies.

Description	Prediction
Total Crashes	269.75
Fatal and Injury Crashes (32%)	86.59
Property-damage-only Crashes (68%)	183.16
Average Future Road ADT (vehicles/day)	14,057
Crash Rate per kilometers per year	5.5
Fatal and Injury Crash Rate per kilometers per year	1.8
Property-damage-only Crash Rate per kilometers per year	3.7
Total travel (million vehicle-kilometers)	253.51
Crash Rate per million vehicle-kilometers	1.1
Fatal and Injury Crash Rate per million vehicle-kilometers	0.3
Property-damage-only Crash Rate per million vehicle-kilometers	0.7

Expected Crash Type Distribution

Table 5: Expected crash type distribution.

Crash Type	Highway Segment	Intersections	Total
Single-vehicle accidents			
Collision with animal	83.4 (30.9%)	0.0 (0.0%)	83.4 (30.9%)
Collision with bicycle	0.8 (0.3%)	0.0 (0.0%)	0.8 (0.3%)
Collision with parked vehicle	1.9 (0.7%)	0.0 (0.0%)	1.9 (0.7%)
Collision with pedestrian	1.3 (0.5%)	0.0 (0.0%)	1.3 (0.5%)
Overturned	6.2 (2.3%)	0.0 (0.0%)	6.2 (2.3%)
Ran off road	75.8 (28.1%)	0.0 (0.0%)	75.8 (28.1%)
Other single-vehicle accident	9.7 (3.6%)	0.0 (0.0%)	9.7 (3.6%)
Total single-vehicle accidents	179.1 (66.4%)	0.0 (0.0%)	179.1 (66.4%)
Multiple-vehicle accidents			
Angle collision	10.5 (3.9%)	0.0 (0.0%)	10.5 (3.9%)
Head-on collision	5.1 (1.9%)	0.0 (0.0%)	5.1 (1.9%)
Left-turn collision	11.3 (4.2%)	0.0 (0.0%)	11.3 (4.2%)
Right-turn collision	1.6 (0.6%)	0.0 (0.0%)	1.6 (0.6%)
Rear-end collision	37.5 (13.9%)	0.0 (0.0%)	37.5 (13.9%)
Sideswipe opposite-direction	6.5 (2.4%)	0.0 (0.0%)	6.5 (2.4%)
Sideswipe same-direction	7.0 (2.6%)	0.0 (0.0%)	7.0 (2.6%)
Other multiple-vehicle collision	11.1 (4.1%)	0.0 (0.0%)	11.1 (4.1%)
Total multiple-vehicle collisions	90.6 (33.6%)	0.0 (0.0%)	90.6 (33.6%)
Total accidents	269.8 (100.0%)	0.0 (0.0%)	269.8 (100.0%)

Expected Crash Frequencies and Rates by Highway Segment

Table 6: Expected crash frequencies and rates by highway segment- sample (2 sections).

Intersection Name/ Cross Road	Station		Length (km)	Expected No. of Crashes for Evaluation Period	Expected Crash Rates			Expected no. of crashes/year for intersection
	From	To			(crashes/km/yr)	(crashes/million vehicle-km)	Expected Crash Rate /million Entering veh	
		207	0.2070	2.06	1.7	0.51		
	207	322	0.1150	2.36	3.4	1.06		

Expected Crash Frequencies and Rates by Horizontal Design Element

Table 7: Expected crash frequencies and rates by horizontal design element- sample (2 sections).

design Element (Horizontal Curve Number or Tangent)	Station		Length (km)	Expected No. of Crashes for Evaluation Period	Expected Crash Rates	
	From	To			(crashes/km/yr)	(crashes/million vehicle-km)
Tangent	0.000	207.000	0.2070	2.06	1.7	0.51
Curve 1	207.000	322.000	0.1150	2.36	3.4	1.06

Crash Prediction Results Plot

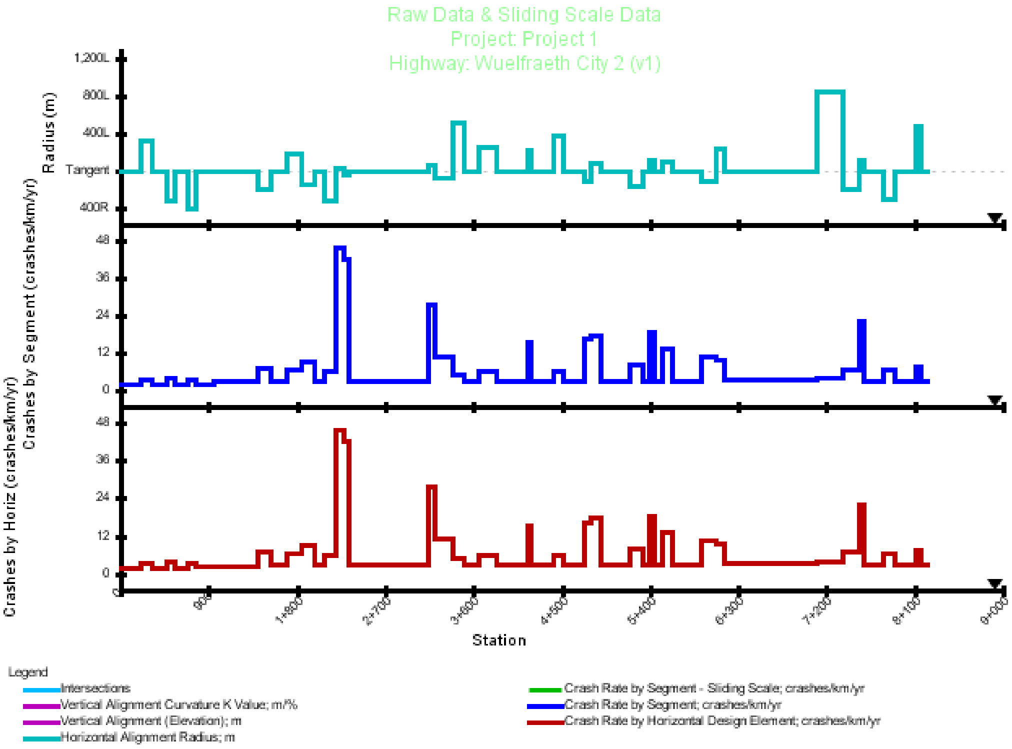

Figure 1: Crash prediction results.

Crash Prediction Evaluation Report- WITH HISTORY

IHSDM Version: 5.0.2 IHSDM 2008 Release

Report Date: Oct 31, 2009 5:03:52 AM

Name: nagham Mehaibes

Project: Project 1 (May 31, 2009 1:57 AM)

Evaluation: CPM (WITH HISTORY) (5:03 AM)

Highway Information: Wuelfraeth City 2 (v1)

Crash Prediction Module Version: 1.4.7 (Nov 20, 2008)

Evaluation Length: 8.2350 kilometers

Crash History Data: 2003 to 2004 (2 years)

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Highway Segment Summary

Table 1: Proposed highway segment data-sample (3 sections).

#	Station		Length (m)	Lane Width		Shoulder Width		Shoulder Type		Driveway Density	Roadside Hazard	Horiz. Curve	Grade %	Passing Lane		Center TWLTL
	Start	End		R	L	R	L	R	L	(dwys/km)	Rating	Number		R	L	
1	0	207	207.00	4.25	4.25	0.0	0.0	N/A	N/A	1.0	5.0	-	3.00	no	no	no
2	207	322	115.00	4.25	4.25	0.0	0.0	N/A	N/A	1.0	5.0	1	3.00	no	no	no
63	8+170	8+235	65.00	3.70	3.70	0.0	0.0	N/A	N/A	3.0	6.0	-	2.50	no	no	no

Horizontal Curve Summary

Table 2: Proposed horizontal curve data- sample (3 sections).

Horizontal Curve Number	Station		Length of Curve (m)	Radius (m)	Superelevation (%)	Design Speed (km/h)	Spiral Transition
	Start	End					
1	207	322	115	320	Left 2.0 adverse Right 2.0	80	none
2	472	562	90	325	Left 2.0 Right 2.0 adverse	80	none
3	682	776	94	400	Left 2.0 Right 2.0 adverse	80	none

Current Segment Traffic Volume

Table 3: Current segment traffic volume.

Segment #	Station		Before Period ADT (veh/day)	
	Start	End	2003	2004
1 to 7	0	953	8,844	8,844
8 to 63	953	8+235	14,739	14,739

Proposed Segment Traffic Volume

Table 4: Proposed segment traffic volume.

Segment #	Station		Evaluation Period ADT (veh/day)					
	Start	End	2010	2011	2012	2013	2014	2015
1 to 7	0	953	8,844	8,844	8,844	8,844	8,844	8,844
8 to 63	953	8+235	14,739	14,739	14,739	14,739	14,739	14,739

Expected Crash Rates and Frequencies

Table 5: Expected crash rates and frequencies.

Description	Prediction
Total Crashes	122.11
Fatal and Injury Crashes (37%)	45.36
Property-damage-only Crashes (63%)	76.75
Average Future Road ADT (vehicles/day)	14,057
Crash Rate per kilometers per year	2.5
Fatal and Injury Crash Rate per kilometers per year	0.9
Property-damage-only Crash Rate per kilometers per year	1.6
Total travel (million vehicle-kilometers)	253.51
Crash Rate per million vehicle-kilometers	0.5
Fatal and Injury Crash Rate per million vehicle-kilometers	0.2
Property-damage-only Crash Rate per million vehicle-kilometers	0.3

Expected Crash Frequencies and Rates by Highway Segment

Table 6: Expected crash frequencies and rates by highway segment- sample (2 sections).

Intersection Name/ Cross Road	Station		Length (km)	Expected No. of Crashes for Evaluation Period	Expected Crash Rates			Expected no. of crashes/year For intersection
	From	To			(crashes/km/yr)	(crashes/million vehicle-km)	Expected Crash Rate /million entering veh	
	0.	207	0.2070	2.58	2.1	0.64		
	207	322	0.1150	2.82	4.1	1.27		

Expected Crash Frequencies and Rates by Horizontal Design Element

Table 7: Expected Crash Frequencies and Rates by Horizontal Design, element- sample (2 sections).

Design Element (Horizontal Curve Number or Tangent)	Station		Length (km)	Expected No. of Crashes for Evaluation Period	Expected Crash Rates	
	From	To			(crashes/km/yr)	(crashes/million vehicle-km)
Tangent	0	207	0.2070	2.58	2.1	0.64
Curve 1	207	322	0.1150	2.82	4.1	1.27

Expected Crash Type Distribution

Table 8: Expected crash type distribution.

Crash Type	Highway Segment	Intersections	Total
Single-vehicle accidents			
Collision with animal	37.7 (30.9%)	0.0 (0.0%)	37.7 (30.9%)
Collision with bicycle	0.4 (0.3%)	0.0 (0.0%)	0.4 (0.3%)
Collision with parked vehicle	0.9 (0.7%)	0.0 (0.0%)	0.9 (0.7%)
Collision with pedestrian	0.6 (0.5%)	0.0 (0.0%)	0.6 (0.5%)
Overturned	2.8 (2.3%)	0.0 (0.0%)	2.8 (2.3%)
Ran off road	34.3 (28.1%)	0.0 (0.0%)	34.3 (28.1%)
Other single-vehicle accident	4.4 (3.6%)	0.0 (0.0%)	4.4 (3.6%)
Total single-vehicle accidents	81.1 (66.4%)	0.0 (0.0%)	81.1 (66.4%)
Multiple-vehicle accidents			
Angle collision	4.8 (3.9%)	0.0 (0.0%)	4.8 (3.9%)
Head-on collision	2.3 (1.9%)	0.0 (0.0%)	2.3 (1.9%)
Left-turn collision	5.1 (4.2%)	0.0 (0.0%)	5.1 (4.2%)
Right-turn collision	0.7 (0.6%)	0.0 (0.0%)	0.7 (0.6%)
Rear-end collision	17.0 (13.9%)	0.0 (0.0%)	17.0 (13.9%)
Sideswipe opposite-direction	2.9 (2.4%)	0.0 (0.0%)	2.9 (2.4%)
Sideswipe same-direction	3.2 (2.6%)	0.0 (0.0%)	3.2 (2.6%)
Other multiple-vehicle collision	5.0 (4.1%)	0.0 (0.0%)	5.0 (4.1%)
Total multiple-vehicle collisions	41.0 (33.6%)	0.0 (0.0%)	41.0 (33.6%)
Total accidents	122.1 (100.0%)	0.0 (0.0%)	122.1 (100.0%)

Crash Prediction Results Plot

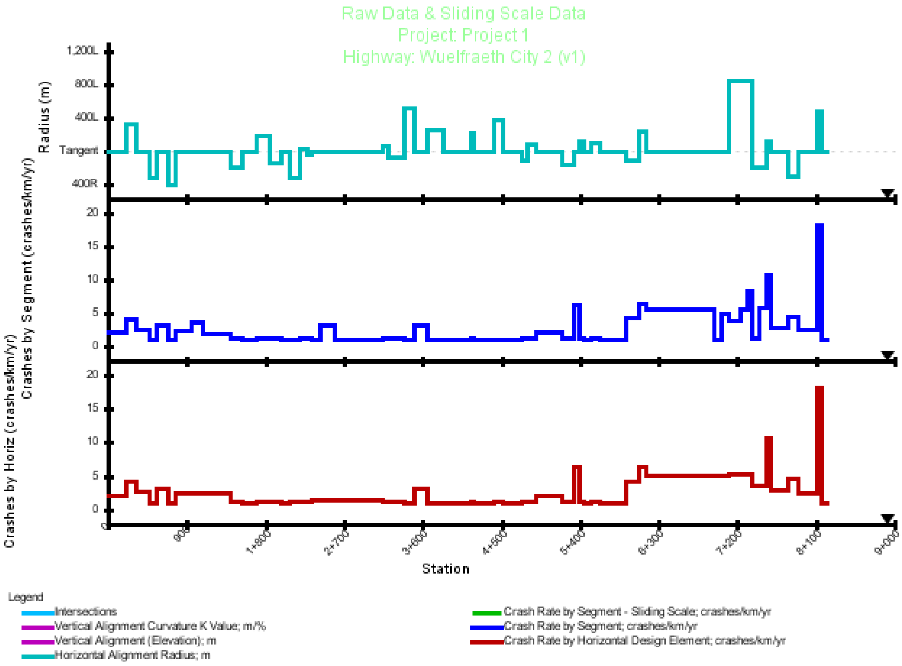

Figure 1: Crash prediction results.

Design Consistency Evaluation Report

IHSDM Version: 5.0.2 IHSDM 2008 Release

Report Date: Oct 31, 2009 5:04:22 AM

Name: nagham Mehaibes

Project: Project 1 (May 31, 2009 1:57 AM)

Evaluation: DCM (5:04 AM)

Highway Information: Wuelfraeth City 2 (v1)

DCM Analysis Vehicle: Passenger Car - Type 5

Vehicle Start Speed: 100 (km/h)

Vehicle End Speed: 100 (km/h)

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Design Consistency Results (increasing stations)

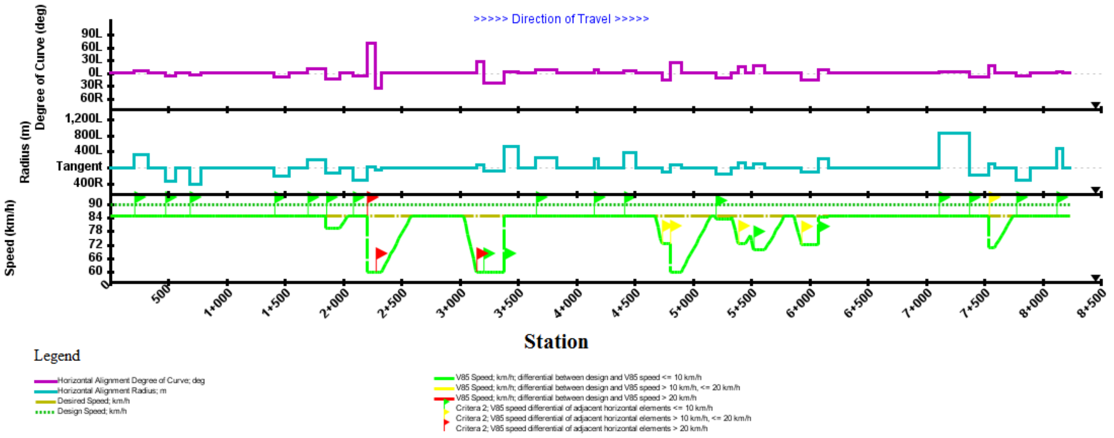

Figure 1: Design consistency results (increasing stations).

Design Consistency Results (decreasing stations)

Figure 2: Design consistency results (decreasing stations).

V85 Speed Profile Coordinates (increasing stations)

Table 1: V85 Speed profile coordinates (increasing stations)-sample (4 sections).

Station	Speed (km/h)
0.000	100
55.556	100
83.333	100
207.000	94

V85 Speed Profile Coordinates (decreasing stations)

Table 2: V_{85} Speed profile coordinates (decreasing stations)- sample (4 sections).

Station	Speed (km/h)
8+235.000	100
8+170.000	98
8+120.000	98
8+056.300	100

Design Speed Assumption Table (increasing stations)

Table 3: Design Speed assumption check (increasing stations)- sample (3 sections).

Station		V85 - Vdesign speed		Condition
From	To	Min (km/h)	Max (km/h)	
0.000	1+384.450	10	20	2
1+384.450	1+572.625	7	10	1
1+572.625	1+666.121	10	15	2

Design Speed Assumption Table (decreasing stations)

Table 4: Design speed assumption check (decreasing stations)- sample (2 sections).

Station		V85 - Vdesign speed		Condition
From	To	Min (km/h)	Max (km/h)	
8+235.000	7+689.951	10	20	2
7+689.951	7+638.303	0	10	1

Design Speed Assumption Check Conditions Key

Condition 1: 0 mph

Condition 2: 6 mph

Condition 3: 12 mph

Condition 4: (V85 - Vdesign)

where:V85 = estimated 85th percentile operating speed (mph), Vdesign = design speed (mph)

Speed Differential of Adjacent Design Elements Table (increasing stations)

Table 5: Speed differential of adjacent design elements check (increasing stations)- sample (3 sections).

Station of Max Speed on Preceding Element	Max Speed on Preceding Element (km/h)	Start Station of Curve	Speed On Curve (km/h)	Speed Differential (km/h)	Condition
0.000	100	207.000	94	6	1
848.344	100	1+408.000	87	13	2
2+203.000	88	2+278.000	60	28	3

Speed Differential of Adjacent Design Elements Table (decreasing stations)

Table 6: Speed differential of adjacent design elements check (decreasing stations)- sample (3 sections).

station of Max Speed on Preceding Element	Max Speed on Preceding Element (km/h)	Start Station of Curve	Speed on Curve (km/h)	Speed Differential (km/h)	Condition
8+235.000	100	8+170.000	98	1	1
7+724.510	97	7+590.000	71	26	3
6+275.306	100	6+160.000	89	11	2

Speed Differential of Adjacent Design Elements Check Conditions Key

Condition 1: 0 mph

Condition 2: 6 mph

Condition 3: 12 mph

where: V85Tangent = estimated 85th percentile operating speed on tangent (mph)

V85Curve = estimated 85th percentile operating speed at the beginning of the curve (mph)

Traffic Analysis Evaluation Report

IHSDM Version: 5.0.2 IHSDM 2008 Release

Report Date: Oct 31, 2009 5:06:10 AM

Name: nagham Mehaibes

Poject: Project 1 (May 31, 2009 1:57 AM)

Evaluation: TAM (5:04 AM)

Highway Information: Wuelfraeth City 2 (v1)

Traffic Analysis Module Version: 1.3.5 (Sep 18, 2008)

Highway Information: Wuelfraeth City 2 (v1)

Processing Limits: 0.000 to 8+235.000

Configuration Data Set: Default (Default TAM configuration file)

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Simulation Input Data

Table 1: Simulation data.

Simulation Time	60.0 (min)
Warm-up Time	10.0 (min)
Total Time	70.0 (min)
Computer Time	6.7 (sec)
Test Road Length	8.2350 (km)

Table 2: Random number seeds.

Entering Traffic in Platoons / Direction of Increasing Stations	81250132
Desired Speed / Direction of Increasing Stations	70867724
Entering Traffic in Platoons / Direction of Decreasing Stations	33333334
Desired Speed / Direction of Decreasing Stations	16532240
Passing Decisions	52338126

Table 3: Traffic input data.

Traffic Input Data	Direction of Travel	
	Increasing Station	Decreasing Station
Flow Rate (v/hr)	890	1470
Distribution (%) CARS	93.0	90.0
Distribution (%) TRUCKS	7.0	10.0
Distribution (%) RVs	0.0	0.0
Mean Desired Speed (km/h) CARS	99	99
Mean Desired Speed (km/h) TRUCKS	96	96
Mean Desired Speed (km/h) RVs	96	96
Desired Speed Standard Speed Deviation (km/h) CARS	8	8
Desired Speed Standard Speed Deviation (km/h) TRUCKS	6	6
Desired Speed Standard Speed Deviation (km/h) RVs	6	6
Entering Traffic in Platoons (%)	79	92
No Passing Zone (%)	0.00	0.00

Simulation Output Data

Table 4: Section summary.

Traffic Output Data	Direction of Travel		
	IncreasingStation	DecreasingStation	Combined
Flow Rate from Simulation (v/hr)	900	1,425	2,325
Percent Time Spent Following (%)	88.2	90.2	89.4
Average Travel Speed (km/h)	56	55	55
Trip Time (min/veh)	8.8	9.0	8.9
Traffic Delay (min/veh)	2.36	2.79	2.62
Geometric Delay (min/veh)	1.38	1.21	1.28
Total Delay (minutes/vehicle)	3.75	4.00	3.90
Number of Passes	8	175	183
Vehicle km Traveled	7,370	11,678	19,048
Total Travel Time (veh-h)	131.4	214.3	345.7

Station Summary (Increasing)

Table 5: Station summary (direction of increasing stations)- sample (2 sections).

section Number	Station	Number of Lanes	Traffic Volume (v/day)	Simulation Speed Characteristic Mean				Percent Following (%)	Platoon Size	Number of Passes
				Cars (km/h)	Trucks (km/h)	RVs (km/h)	All (km/h)			
1	5.000	1	884	99	98	0	98	74.40	6.7	0.0
2	105.000	1	884	97	95	0	97	74.30	6.6	0.0

Station Summary (Decreasing)

Table 6: Station summary (direction of decreasing stations)- sample (2 sections).

station Number	Station	Number of Lanes	Traffic Volume (v/day)	Simulation Speed Characteristic Mean				Percent Following (%)	Platoon Size	Number of Passes
				Cars (km/h)	Trucks (km/h)	RVs (km/h)	All (km/h)			
1	8+205.000	1	1,428	95	94	0	95	84.10	9.5	0.0
2	8+105.000	1	1,429	89	87	0	89	84.00	9.5	0.0

Traffic Analysis (Increasing)

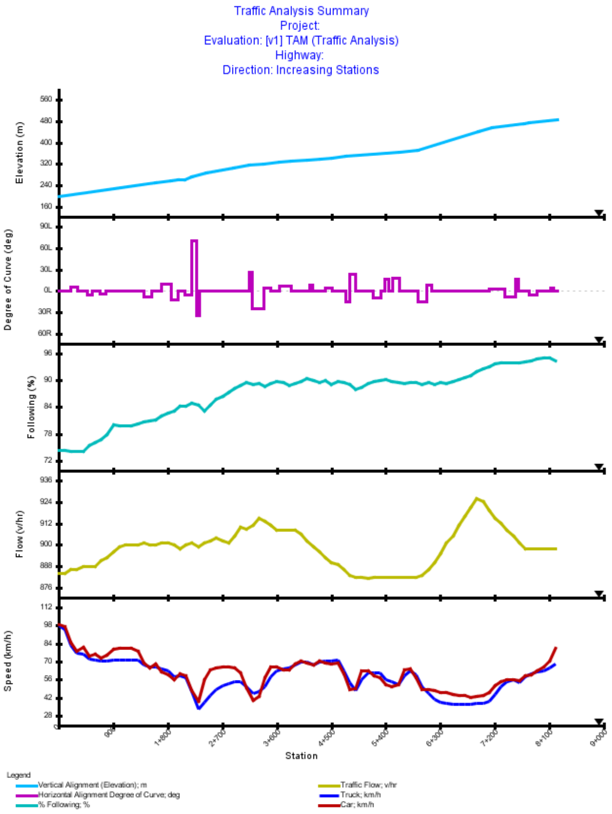

Figure 1: Traffic analysis - increasing stations.

Traffic Analysis (Decreasing)

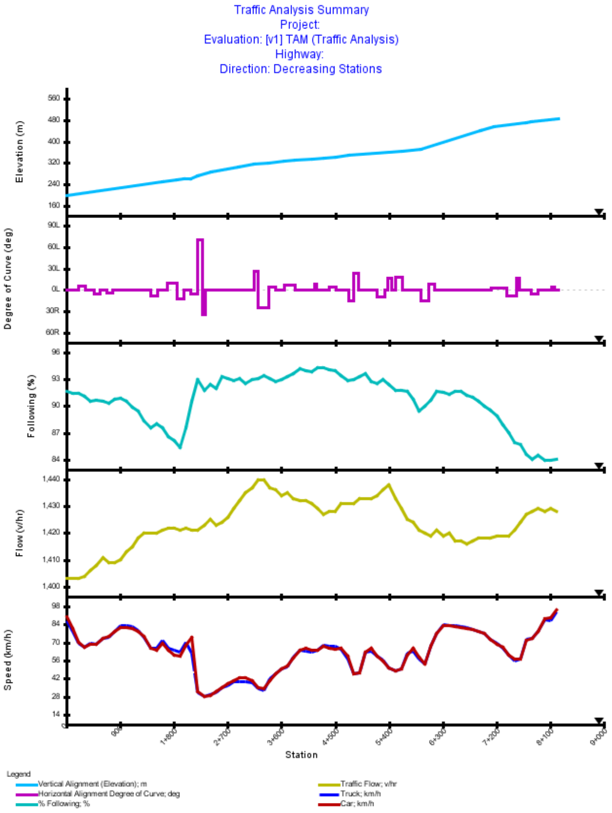

Figure 2: Traffic analysis - decreasing stations.

Driver/Vehicle Evaluation Report

IHSDM Version: 5.0.2 IHSDM 2008 Release

Report Date: Oct 31, 2009 5:07:03 AM

Name: nagham Mehaibes

Project: Project 1 (May 31, 2009 1:57 AM)

Evaluation: DVM (5:06 AM)

Highway Information: Wuelfraeth City 2 (v1)

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Simulation Settings

Table 1: Simulation settings.

Name	Value
Minimum Station	0.0
Maximum Station	8235.0
Direction	increasing
Mode Type	Deterministic
Driver Type	Nominal
Path Type	Center
Vehicle Type	Passenger Car
Number of Trials	1
Report Interval	0.1000
Integration Time Interval	0.0050
Sight Distance Type	both
Seed	123456789
Summary Report Interval	30.00000000

Mean Value of Critical Variables

Table 2: Mean value of critical variables- sample (3 sections).

Station	Lateral Offset (m)	Friction Ratio X	Friction Ratio Y	Roll Over Index	Lateral Friction Demand	Lateral Acceleration (g)	Speed (km/h)
66.000	0.13	-0.04	-0.08	0.04	-0.03	-0.01	69.48
96.000	0.10	-0.06	-0.05	0.03	-0.02	-0.00	69.74
126.000	0.01	-0.07	-0.04	0.03	-0.02	0.00	69.81

DVM Simulation Run

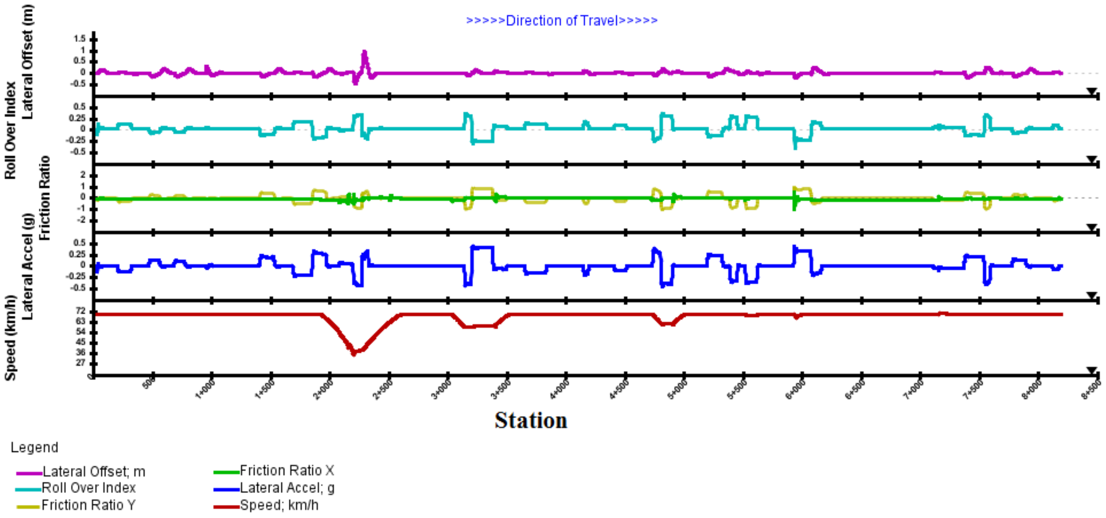

Figure 1: DVM simulation run graph.