APPLICATION OF THE HIGHWAY SAFETY MANUAL 2010 TO TWO ROAD SECTIONS IN WESTERN CAPE

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ABSTRACT

The Highway Safety Manual 2010 provides a new set of methodologies to evaluate or predict safety performance on road sites. It is based on crash data from the United States of America. The paper gives a brief introduction to the Highway Safety Manual 2010 and its methodologies. The applicability of these methodologies has not yet been evaluated for South African conditions.

Two sections of route R44 (provincial road M 27) were analysed. Section 1 - between Klapmuts and Stellenbosch - is a single carriageway with shoulders and Section 2 - between Stellenbosch and Somerset West - is a dual carriageway road with at grade intersections. The respective safety performance functions (SPFs), modified by crash modification factors (CMF) were used to estimate the number of crashes. These were compared to the average number of crashes reported over the last 5 years, subject to the proviso that the reported crash data may not be as accurate as that of the USA.

On Section 1, the single carriageway road section, the observed number of crashes was 0,67 times higher than the predicted number, but the observed number of crashes for the intersections and road segments were 0,12 and 0,95 of the predicted number respectively.

The total number of crashes observed for Section 2 on the dual carriageway link sections. was about 4,7 times higher than number predicted. The number of crashes at stop controlled intersections was predicted, but as these intersections were not specified in the accident statistics, the values were added to the sections. The number of observed crashes at traffic signal controlled intersection was 1,1 times higher than the number of predicted crashes.

The evidence presented in this paper indicates that the safety performance functions that were investigated cannot be transferred to the South African situation directly from the USA where they were developed. The logic of the HSM 2010 methodologies seems to be robust. The ranges of values of crash modification factors seem acceptable.

This study did not attempt to explain the reasons why the predicted crash frequency differed from the actual number of crashes, as the road sections on which it was tested is not a representative sample. Local research into the shape and size of the safety performance factors and the calibration of crash modification factors should be promoted. The basis of such research is collision statistics, and every effort should be made to improve the quality of our data capturing system.

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1 INTRODUCTION

I am indebted to Casper Steenkamp and Robert Kotzé, final year students of 2011, who collected and processed the data as part of their final-year dissertations, the Stellenbosch Municipality Traffic Department and Provincial Government Western Cape for data.

The Highway Safety Manual (HSM) 2010 provides a new set of methodologies to evaluate or predict safety performance on road sites. It is based on crash data from the United States of America. The applicability of these methodologies has not been evaluated for South African conditions. The paper therefore aims to compare the outcomes of safety performance functions and crash modification factors developed in the USA to actual safety performance in South Africa.

The HSM is a three-volume book set that was published in January 2010 by the American Association of State Highway and Transport Officials (AASHTO). The aim of the HSM 2010 is to reduce the number and severity of accidents on all roads in the United States by making better use of available technologies and scientific knowledge. It provides the reader with analytical methods to predict the number and severity of accidents that can be expected on United States roads (AASHTO, 2010). The HSM 2010 can be used for evaluating different design alternatives. It can also assist designers when upgrading existing roads to a safer driving environment. The HSM procedures can also calculate the economic benefits from crash reductions.

The Highway Safety Manual 2010 is the first edition of what is proposed to be a living document, to be elaborated, augmented and developed over time to cover a wide range of sites with increasing accuracy. By publishing the HSM, the road safety professionals are invited to analyse, critique, explore and improve the methodologies and accuracies of the data.

The HSM is divided into 4 parts. Part A of the HSM consists of three chapters. Chapter 1 provides an introduction and overview of the HSM. Chapter 2 covers the human factors contributing to accidents. Chapter 3 is an introduction to the fundamental concepts that are used later in the HSM. Part C of the HSM, which includes the predictive method that this paper evaluates, is explained in Chapter 3.5 *Predictive Method in Part C of the HSM*.

Part B consists of chapters 4 to 9. These chapters cover the roadway safety management process. Chapter 4 focuses on network screening which includes methods to rank the different sites or sections. This helps to establish which sites or sections of the road network have the greatest possibilities for safety improvements. Chapter 5 of the HSM includes the diagnosis, which is the second step in the road safety management process. The diagnosis provides an understanding of accident patterns by including previous studies and physical characteristics of the road under investigation. The focus of Chapter 6 is the selection of countermeasures to reduce the number and severity of the accidents. This is step three of the safety management process. The economical appraisal, step four of the safety management process is discussed in Chapter 7. In this chapter the economic benefits in safety measures are evaluated against the project cost. In some instances it may not be viable to continue with a safety enhancing project because of it might just be too expensive. In Chapter 8 the steps for prioritizing projects are given. It is, in most cases, not possible to do all the safety enhancing projects all at once. In order to have the fastest and largest effect on the road safety, it is important to do the right projects first. It is also important to evaluate the changes that have been made on roadways in order to enhance road safety. Chapter 9 focuses on these measures to evaluate the changes and their effectiveness.

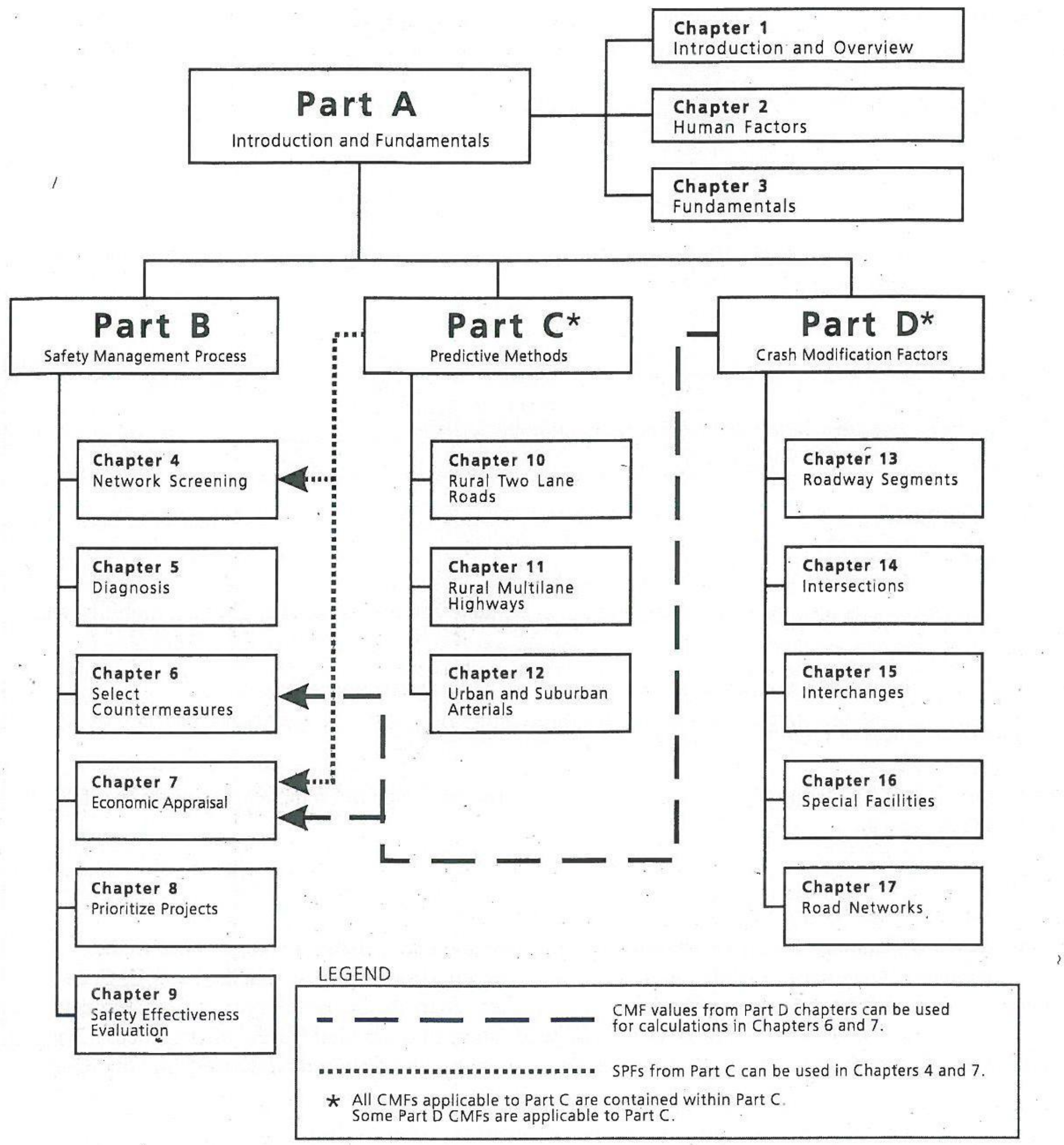

Figure 1-1. Organization of the Highway Safety Manual

Figure 1: Organization of the Highway Safety Manual
Source: HSM, 2010, p I-5

Part C of the HSM presents the three different safety performance functions (SPF) that estimate the expected number of accidents for various road sections. Chapter 10 sets out the predictive method for rural two-lane, two-way roads. Chapter 11 sets out the predictive method for rural multilane highways. Chapter 11 sets out to predict the number of accidents that can be expected for four-lane divided roadways. In Chapter 12 the focus is on the predictive method's calculations for urban and suburban arterials.

Part D of the HSM contains the crash modification factors (CMFs) by which the predictive method’s results can be adjusted for the different road segments’ specific design characteristics. The purpose of part D is to present information regarding the different design alternatives for each specific type of road segment. The CMFs for general roadway segments can be found in Chapter 13. Chapter 14 contains the CMFs for intersections, and Chapter 15 for Interchanges. Chapter 16 presents the information regarding special facilities and geometric situations. Chapter 17 of the HSM contains the CMFs for road networks. The CMFs that the HSM present can also be used in Chapters 6 and 7 to calculate the value of a potential reduction of accidents.

The paper will refer extensively to SPF and CMR, which are defined as:

- Safety Performance Function: a mathematical relationship for safety performance based upon exposure and road conditions.
- Crash Modification Factor: a proportion by which a change in the base condition of a road feature can change the expected number of accidents.

Only certain Safety Performance Functions have been included in the current HSM, 2010. The selection of the road sections to be studied was dictated by this. The functions available are shown in Figure 2.

Exhibit C-2: Safety Performance Functions by Facility Type and Site Types in Part C

HSM Chapter/ Facility Type	Undivided Roadway Segments	Divided Roadway Segments	Intersections			
			Stop Control on Minor Leg(s)		Signalized	
			3-Leg	4-Leg	3-Leg	4-Leg
10 - Rural Two-Lane Two-Way Roads	✓	-	✓	✓	-	✓
11 - Rural Multilane Highways	✓	✓	✓	✓	-	✓
12 - Urban and Suburban Arterials	✓	✓	✓	✓	✓	✓

Figure 2: Available Safety performance factors.
Source: Exhibit C-2: The HSM Predictive Method, HSM, 2010

The HSM predictive method is exposure based and as such, the traffic volume is an important variable. The acronym AADT is therefore found in the SPFs: it stands for Average Annual Daily Traffic, which is the total traffic flow for a 365 day period divided by 365 days. Average Daily Traffic (ADT), which is an average based on any period shorter than 365 days, is sometimes used in absence of AADT.

Figure 3 shows the steps of the HSM Predictive Model.

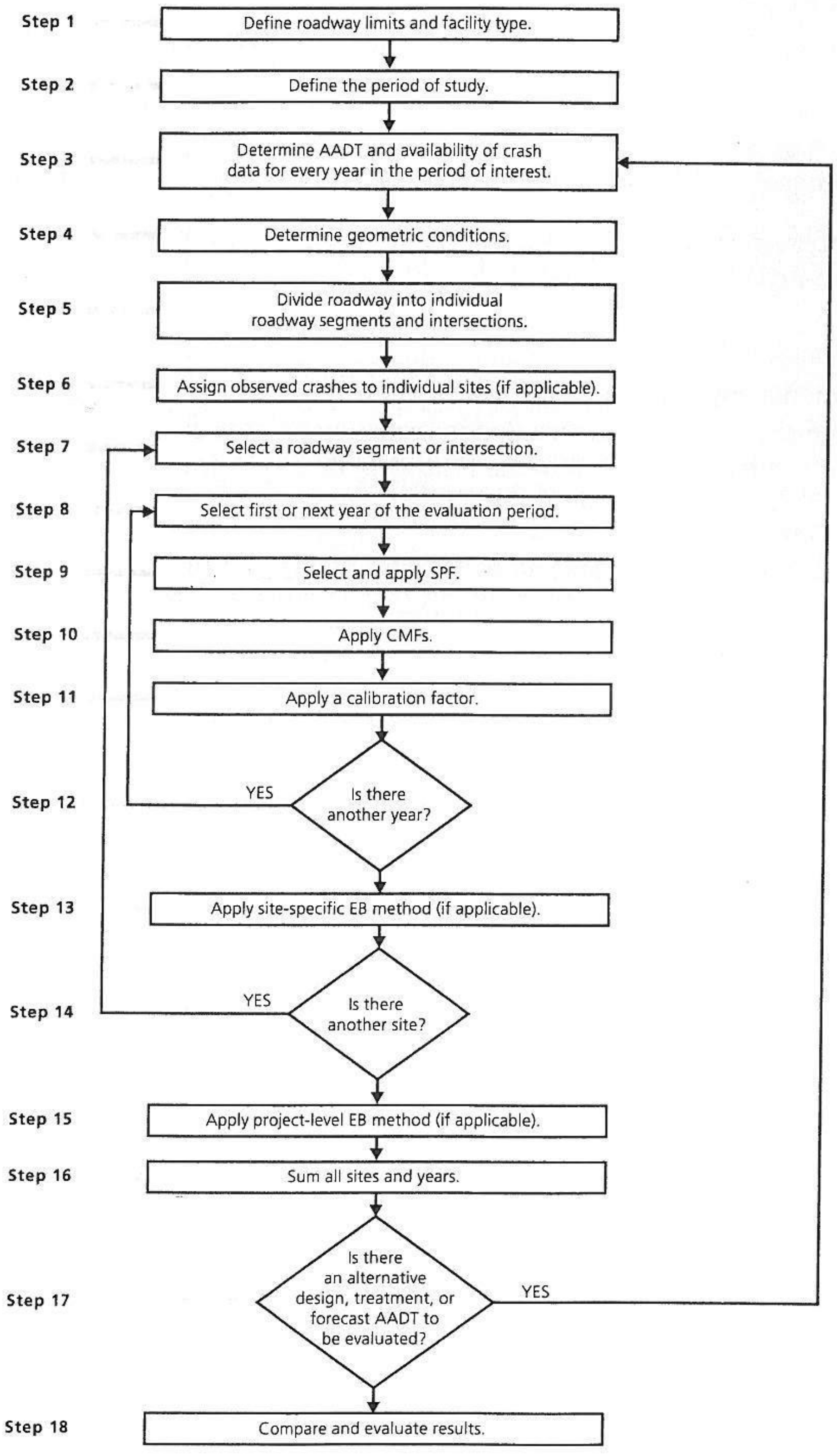

Figure C-2. The HSM Predictive Method

Figure 3: The Highway Safety Manual Predictive Model
Source: HSM, 2010, p C-6

2 DATA COLLECTION

Two sections were included in the studies:

- Section 1: between Stellenbosch and Klapmuts, a two lane, two way road with stop controlled junctions.
- Section 2: between Stellenbosch and Somerset West, a four lane, dual carriageway road with traffic signal controlled intersections at major cross roads and minor access roads that were included in the link section analysis.

Traffic accident statistics for the Route R44 were obtained from the Provincial Administration of the Western Cape and from the Stellenbosch Traffic Department. Traffic count data on Section 1 was obtained from the provincial roads department. The traffic counts were only available for the main road and estimates for the side road traffic were made from peak hour counts. Traffic counts on the dual carriageway section, Section 2, for the intersections near Stellenbosch were obtained from the Stellenbosch Municipality: these were counted in 2008 as part of a local transport plan. The traffic volumes for the outlying intersections were based on the provincial traffic data for the main road and estimates based on peak hour counts for the side roads. The sections are shown in Figure 4.

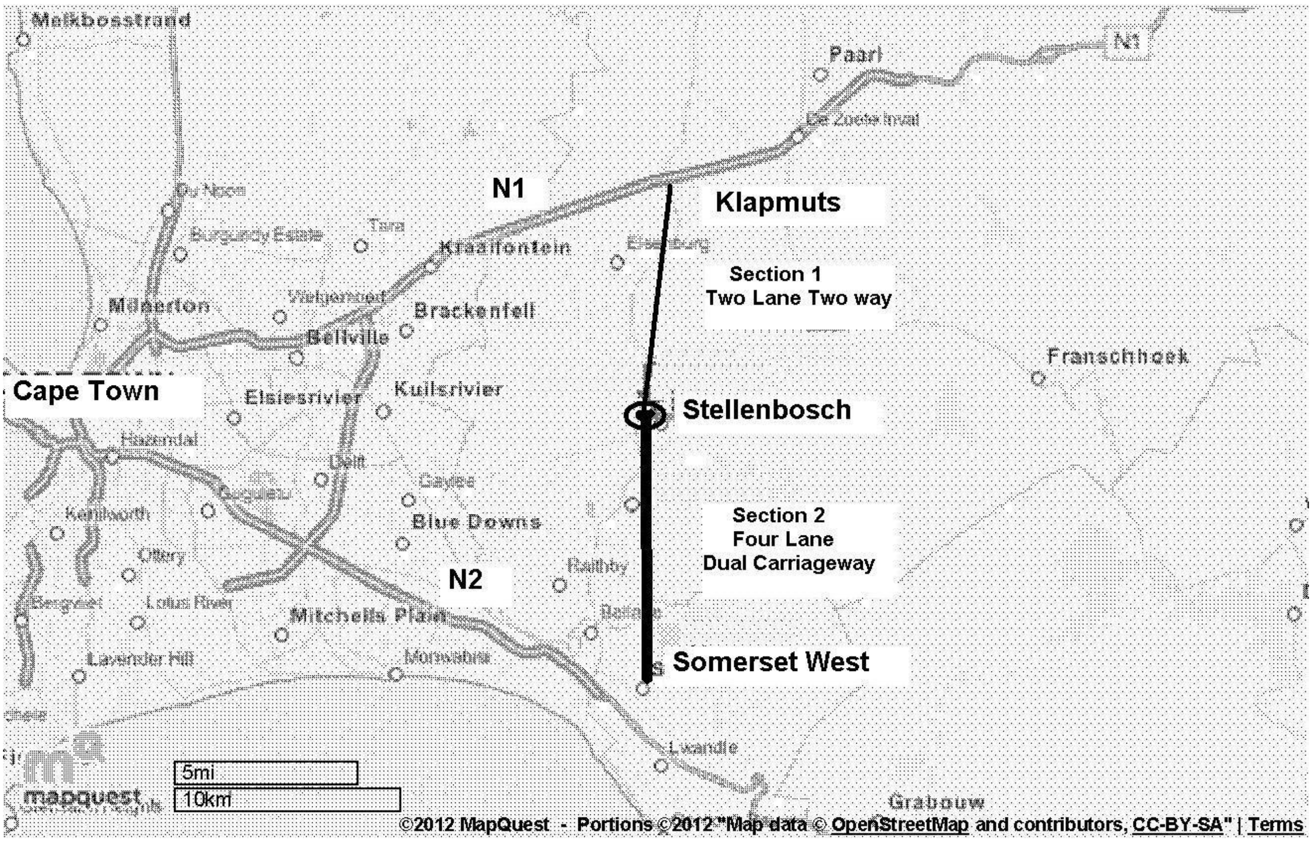

Figure 4: Locality Plan for Sections of Route R44
(Source: MapQuest)

3 ANALYSIS

The comparison of predicted to observed crashes was restricted to the total number of crashes to obtain a provisional assessment of the applicability of the HSM methodologies. This simplification is open to criticism, such as the lower reliability of total number of crashes compared to that of fatal crashes, due to underreporting of damage-only crashes. A full analysis, including crash severity and collision types, will only be attempted in a more extensive and representative study.

The general form of the predicted average crash frequency is given in HSM, 2010, p10-2:

$$N_{predicted} = N_{spfx} \text{ x } (CMF_{1x} \text{ x } CMF_{2x} \text{ x....x } CMF_{yx}) \text{ x } C_x$$

Where:

$N_{predicted}$	= predicted average crash frequency for a specific year for site type x;
N_{spfx}	= predicted average crash frequency for base conditions of the SPF developed for site type x;
CMF_{1x}	= crash modification factors specific to site type x and specific geometric design and traffic control features y
C_x	= calibration factor to adjust SPF for local conditions for site type x.

Neither a calibration factor nor the Empirical Bayes methodology was used in this analysis, as it is an attempt to assess the extent to which the USA base predicted crash frequency differs from the observed values.

3.1 Section 1 (R44): Two way two lane section with intersections.

The sample road is 12 km long and is divided into 3 road segments and 4 T-junctions with stop control on the minor legs. A traffic signal controlled junction at the southern end of the sample road was omitted as the crash history was compromised due to rapid growth of the Welgevonden Estate and with associated changes to the lane layout.

The SPF for 3 leg stop controlled intersections is shown in Figure 5.

Three-Leg Stop Controlled Intersection (3ST)

$$N_{spf3ST} = \exp[-9.86 + 0.79 \times \ln\ AADT_{maj} + 0.49 \times \ln\ AADT_{min}\ ]$$

Figure 5: SPF for 3ST intersection on undivided roads
Source: HSM, 2010

The intersections are marked A, C, E and F. The variables of the intersections were substituted in the SPF for stop controlled intersections. Crash Modification Factors (CMF) evaluate the effects of intersection approach angle, protected right turns, protected left turns and intersection lighting. In all the cases, the base conditions for application of the SPF were met and the CMFs are all equal to 1. The estimated numbers of crashes is shown in the Table 1.

Table 1: Estimated numbers of crashes at intersections on Section 1 (R44)

Intersection	AADT $_{major}$ veh/day	AADT $_{minor}$ veh/day	N $_{sp3ST}$
A	13 960	3 500	5,35
C	12 270	1 150	2,81
E	14 000	2 850	4,85
F	14 000	650	2,35

The 3 road sections were similarly analysed using the SPF for road sections shown in Figure 6. The lengths of road were converted to mile for use in the SPF.

$$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$$

Figure 6: SPF for two way two lane road segments
Source: HSM, 2010

The sections were marked B, D and G. The estimated numbers of crashes are shown in Table 2. The SPF for two way, two lane road segments is valid up to 17 800 veh/day. These AADT's are either within the boundaries or only slightly over.

The CMFs were calculated and are shown in Table 2. The CMFs for two lane two way road sections are based on lane widths, shoulder width and type, horizontal alignment, superelevation, vertical curves, access density, sleeper lines on the road center line, passing, climbing and protected right turn lanes, a roadside hazard rating, road lighting and speed cameras. Not all of these elements conformed to the basis values and some of the CMFs were thus greater than 1. The resultant CMFs increase the number of crashes between 11 and 21%. The detail of the calculations was omitted for the sake of brevity.

Table 2: Estimated number of crashes on two way two lane sections

Road section	AADT veh/day	Length km	CMF	N $_{rd}$
B	12 070	5,82	1,2073	14,17
D	12 850	1,92	1,1178	4,79
G	18 160	4,41	1,1456	15,23

3.2 Section 2 (R44) divided rural multilane road with intersections.

The sample road is approximately 10 km long and was divided into 5 traffic controlled intersections, 6 stop controlled T-junctions and 6 dual roadway sections with accesses.

Two of the traffic signal controlled intersections are 3 way intersections, for which there are no SPFs as yet. These intersections were evaluated as 4 way intersections, which would be more conservative (more crashes should be predicted).

The SPF for 4SG intersections is as below, with the calibration constants in the table below:

$$N_{spf\ int} = \exp^{(a + b \times \ln (AADTmajor + c \times (AADT\ minor)}$$

Intersection Type/ Severity of accident	a	b	c	d	Over dispersion Parameter (Fixed k)
4SG Total	-7.182	0.722	0.337	-	0.277
4SG Fatal and injury	-6.393	0.638	0.232	-	0.218
4SG Fatal and injury[b]	-12.011	-	-	1.279	0.566

Figure 6: SPF and Calibration constants for 4SG intersection
Source: HSM, 2010

The variables and estimated numbers of crashes were calculated for the 5 traffic signal controlled intersections and the results are shown in Table 4.

Table 3: Estimated number of crashes: traffic signal controlled intersections Section 2

Intersection	$AADT_{major}$	$AADT_{minor}$	$N_{int\ 4SG}$
Van Rheede	24 730	8 030	23,38
Blaawklippen	25 910	3 760	18,71
Technopark	25 540	4 640	19,89
Webersvalley	24 070	4 320	18,59
Annandale	20 020	3 070	14,51

Stop controlled intersections occur over the length of Section 2 (R44). The same SPF as was used for the traffic signal controlled intersections was used, but with different calibration constants. Figure 7 shows the constants for the two situations.

Intersection Type/ Severity of accident	a	b	c	Over dispersion Parameter (Fixed k)
4ST Total	-10.008	0.848	0.448	0.494
4ST Fatal and injury	-11.554	0.888	0.525	0.742
4ST Fatal and injury[a]	-10.734	0.828	0.412	0.655

Intersection Type/ Severity of accident	a	b	c	Over dispersion Parameter (Fixed k)
3ST Total	-12.526	1.204	0.236	0.460
3ST Fatal and injury	-12.664	1.107	0.272	0.569
3ST Fatal and injury[a]	-11.989	1.013	0.228	0.566

Figure 7: Calibration constants for 4ST and 3ST intersection SPFs
Source: HSM, 2010

Table 4 shows the estimated number of crashes at the stop controlled intersections.

Table 4: Estimated number of crashes at stop-controlled intersections on Section 2 (R44)

Intersection	AADT $_{major}$	AADT $_{minor}$	CMF	N $_{int\ 4ST}$	N $_{int\ 3ST}$
Peeka	24 850	310	0,66		1,83
Paradyskloof	24 400	950	0,47	1,26	
Forest	19 230	30	0,84		2,40
Winery	16 770	1 600	1,032		2,61
Sondans	18 090	160	1,059		1,71
Bredell	18 860	700	1,112	3,99	

The SPF for the multilane dual roadway and the calibration constants are given below:

$$N_{spf\ rd} = e^{(a+b \times \ln AADT + \ln L)}$$

Severity Level	a	b	c
4-Lane total	-9.025	1.049	1.549
4-Lane fatal and injury	-8.837	0.958	1.687
4-Lane fatal and inury[a]	-8.505	0.874	1.740

Figure 8: SPF and Calibration constants for 4 lane dual roadway
Source: HSM, 2010

The variables and estimated numbers of crashes on the dual road sections are shown in Table 5. In this section, various CMFs were applied, as some of the base conditions were not met. The calculation of the CMFs is not indicated.

Table 5: Estimated number of crashes on multilane sections

Section	AADT Veh/day	Length km	CMF	N $_{predicted}$
Parmalat	27 960	1,7	0,944	5,87
Gholf Course	26 060	1,0	0,935	2,70
Mushroom farm	25 060	0,7	0,935	2,01
Airfield	22 890	3,0	1,025	8,61
Mooiberge	18 920	3,2	1,035	7,59
Winery	18 260	1,4	1,035	3,20

4 COMPARISON WITH COLLISION DATA

Data from the Western Cape Provincial Government, for the 5 year period, 2006 to 2010, was used to calculate the average number of crashes per year for Section 1. Collision data from the Stellenbosch Traffic Department's Accident Section, for the 5 years March 2006 to March 2011, was used for Section 2.

4.1 Section 1 (R44)

The comparison of predicted to actual crash data for the sites on Section 1 (R44) is summarised in Table 6:

Table 6: Comparison of crash data for sites on Section 1 (R44).

Site	Predicted	Actual	Ratio
Intersections A	5.35	1.8	0.37
Intersections C	2.81	0	
Intersections E	4.85	0	
Intersections F	2.35	0	
Subtotal	*15.36*	*1.8*	*0.12*
Link section B	14.17	29.6	2.089
Link section D	4.79	1.0	0.209
Link section G	15.23	2.0	0.131
Subtotal	*34.19*	*32.6*	*0.953*
Total	**49.7**	**34.4**	**0.672**

4.2 Section 2 (R44)

The comparison of the collision data for Section 2 is shown in Tables 7a, b and c.

Table 7a: Comparison of intersection crash data for sites on Section 2 (R44)

Site	Predicted	Actual	Ratio
Van Rheede	23.38	5.5	0.235
Blaawklippen	18.71	5.5	0.293
Technopark	19.89	31.2	1.568
Webersvalley	18.59	32	1.721
Annandale	14.51	31.4	2.164
Total	95.08	105.6	1.110

Table 7b shows the combined individual road section crash data with the stop control data of stops that occur in the appropriate section. Stop controlled intersections are marked *.

Table 7b: Comparison of link section crash data for sites on Section 2 (R44)

Site	Predicted	Section	Actual	Ratio
Peeka*	2.8			
Paradyskloof*	5.1			
Parmalat	5.87	13.77	36.4	2.64
Golf Course	2.7	2.7	35.3	13.07
Mushroom Farm	2.01	2.01	52.2	25.97
Forest*	1.2			
Stellenbosch Square	8.61	9.81	49.4	5.04
Mooiberge	7.56	7.56	34.3	4.54
Winery*	2.5			
Sondans*	1.6			
Bredell*	3.6			
Winery Road	3.2	10.9	15.4	1.41
Total		**46.75**	**223**	**4.7**

Table 7c Comparison of crash data on whole of Section 2 (R44)

Site	Predicted	Actual	Ratio
Section 2 (R44)	141.83	328.6	2.32

5 FINDINGS

The findings are only valid insomuch as they are based on the available crash data on the specific road sections of Route R44. The Safety Performance Functions for selected road sections and intersections were computed and compared with available crash data. The ratios of predicted crashes to actual crashes were as follows:

On the two way two lane road:

- stop controlled intersections: 0.12
- road sections: 0.95
- over the whole of the road: 0.67

On 4 lane divided road traffic

- signal controlled intersections: 1.1
- road sections including minor stop controlled intersections 4.7
- whole of the road 2.3

The extent to which the ratios vary is so great that the HSM 2010 SPFs cannot be regarded as reliable for use in South Africa. The lack of correlation between the USA predictions and SA results may be due to various factors, such as different driving cultures, vehicle fleets and poor data. The road sections in this study are not statistically representative of the rural road network and the results of this study cannot be extrapolated as such.

6 CONCLUSIONS

This investigatory study into the applicability of the HSM 2010 to South African roads is not statistically reliable, but serves to illustrate that the methodology must be researched before it can be implemented locally. The Safety Performance Functions proposed in the Highway Safety Manual 2010 cannot be applied directly in South Africa. The Crash Modification Factor appears to be more robust but need to be validated.

This study did not attempt to explain the reasons why the predicted crash frequency differed from the actual number of crashes, as the road sections on which it was tested is not a representative sample. Local research into the shape and size of the safety performance factors and the calibration of crash modification factors should be promoted. The basis of such research is collision statistics, and the improvement of local crash data is a prerequisite for research into road safety.

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