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Predictive models for road crashes at intersections

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Abstract

This report deals with the development of appropriate predictive models for crashes at intersections capable of being used in planning purposes. It begins with a brief review of past studies into the relationship between crashes at intersections and traffic flow. All crashes occurring between 1988-1991 at 115 signalised intersections and 10 roundabouts in metropolitan Adelaide are assembled in a database. Summary descriptive statistics are provided showing the proportion of crashes by the main crash types. Comparison between the crash situations at signalised intersections in Adelaide and Perth (WA) is provided in tabular form. Cross-sectional study providing a comparison between the crash situation at roundabouts and signalised intersections with similar traffic flow is presented. Non linear and multiple linear regression methods are used to develop models for total intersection crashes and the main collision types at signalised intersections. The frequency of each of the main crash types are related to traffic flow movements contributing to the occurrence of that type of collision. The report concludes with a set of guidelines to be adopted in developing models for the various crash types at intersections.

Keywords

road crashes, planning, predictive models, traffic management, accident database

Report of FORS Funded Research Project

PREDICTIVE MODELS FOR ROAD CRASHES AT INTERSECTIONS

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SUMMARY

Most road collisions on urban road networks occur at intersections. The major intersections which contribute to majority of these crashes, are most often controlled by either signals or roundabouts. While the reason for these are varied and complex, a significant part may be attributed to the built environment in terms of both the physical and traffic management systems. This study deals with developing appropriate predictive models for crashes at intersections capable of being used in planning purposes. The report begins with a brief review of past studies into the relationship between crashes at intersections and traffic flow. All crashes occurring between 1988-1991 at 115 signalised intersections and 10 roundabouts in metropolitan Adelaide are assembled in a database. Summary descriptive statistics are provided showing the proportion of crashes by the main crash types. Comparison between the crash situations at signalised intersections in Adelaide and Perth (WA) is provided in tabular form. Cross-sectional study providing a comparison between the crash situation at roundabouts and signalised intersections with similar traffic flow is presented. These results are presented in tables and charts.

Non linear and multiple linear regression methods are used to develop models for total intersection crashes and the main collision types at signalised intersections. The frequency of each of the main crash types is related to the traffic flow movements contributing to the occurrence of that type of collision. The developed models are validated using an independent data set from WA to assess their predictive capabilities in different areas. The main findings include the following.

- Valid predictive models can be developed by relating the various crash types to the traffic movements contributing to their occurrence.

- The various crash types relate to different functional forms of the flow exposure measure used indicating that the appropriate approach to be adopted in developing models for crash at signalised intersections is to disaggregate the crashes by type and develop separate models for each crash type.

- The square root of the cross product of flow first suggested by Tanner (1953) is the best predictor of crashes at intersections is confirmed.

- Models developed for one region may not be appropriate for use in another area of different crash rate and signal operations.

- It may be necessary to develop separate models for the CBD and suburban areas in one metropolitan area if the traffic conditions and signal operations are different (as in the case of Adelaide.

- Approach based models enable the introduction of specific site and signal factors into the regression equation. Hence this is the best approach to take if one wants to investigate the influence of the intersection and signal factors on the occurrence of collisions.

The report concludes with a set of guidelines to be adopted in developing models for the various crash types

1.0 INTRODUCTION

1.1 GENERAL

Large numbers of accidents occur at intersections in urban road networks. While the reasons for this problem are varied and complex, a significant factor is the environment, in terms of both physical and traffic management systems. Considerable research and expenditure has been devoted to providing a safe physical environment but there has been perhaps less emphasis on road safety aspects in the planning of traffic management schemes. This is due in part, to a lack of effective tools for predicting accident rates from the pattern of intersections and traffic flow volumes. Research into the relationships between traffic flow and accidents at intersections has been very limited and the results inconsistent.

This report provide a comparison between the road accident rates and frequencies at intersection controlled by signals and roundabouts in South Australia (SA) and Western Australia (WA), the verification of the predictive models developed by Hughes using an independent data set from SA, and finally the development of improved predictive models by regression methods. The basic independent variable used is the traffic flow using the intersection which is supplemented by some intersection geometry and signals variables. The introduction of the intersection and signal factors will throw some light on the those factors which influence road crash occurrences at signalised intersections. At traffic signalised intersections, differences exist in the signal operations and the site geometry on the various approaches of the intersections. Hence aggregating the number of accidents into a total and developing one model for the whole intersection may obscure some important variables. As a result separate models will be developed for each of the four main accidents types at signalised intersections: rear end, side swipe, right angle and right turn accidents on an approach basis. This will make it possible to relate each crash type to the traffic movements contributing to that type of collision. This is a first step towards a proactive approach to urban road safety through the development and adoption of area traffic management schemes that balance road safety and traffic flow considerations.

1.2 BACKGROUND

There exist a number of methodologies and software packages developed for planning traffic management schemes at intersections and across a local area (eg MULATM, see Taylor (1989)). These techniques allow the traffic engineer to compare alternative scenarios in terms of the predicted traffic volumes and delays and other standard measures of traffic flow, but they have not directly included the road safety implications of a particular intersection design. This makes it difficult to adequately compare alternatives and make decisions on the basis of all relevant factors. Indeed there is a danger that safety will be dominated by other factors for which there are readily available and comparable quantitative prediction models. The solution is to include quantitative predictions of road safety implications as an integral component of the planning and evaluation process. The aim of this project is to begin the development of such tools.

Previous work on predicting accident rates has focused on the relationship between accidents and traffic flow at isolated intersections, see Satterthwaite (1981) for a review of overseas studies and Hughes (1991) for an Australian perspective. Hughes (1991) considered only certain types of signalised intersections in WA, and this appears to be the only previous study of predictive models under Australian conditions. These studies have produced patchy but encouraging results, and have identified some broad qualitative principles. There appears to be considerable scope for refining the models and methodologies to produce more accurate, robust and general models to meet Australian conditions. The main thrust of the project is to investigate the development of general methodologies and models for predicting accidents rates at intersections under Australian traffic conditions, and the potential for incorporating these techniques into the general planning and evaluation process for traffic management schemes.

1.3 STUDY OBJECTIVES

The main objectives of the project are as outlined below:

1. develop accurate, robust and general models that link accidents rates at signalised intersections to traffic flow conditions for specific types of intersection and road user movements.

2. test the generality of previous predictive models and verify the models produced by Hughes (1991) for WA in the wider Australian context.

3. develop improved models and/or methodologies for predicting accident rates under South Australian conditions

4. determine whether the models have broader applications

5. assess the potential for developing standard predictive methodologies and models in an Australian context.

6. undertake preliminary investigation of methodologies for incorporating accident prediction into the planning process for traffic management on a single site and local area basis

7. disseminate information on predictive models to interested parties (eg. state road transport authorities, local government)

8. to simulate debate on the role of predictive models

1.4 STUDY DESIGN

The study was conducted in the following stages:

1. review of the state of the art in models for predicting accidents at intersections
2. the selection and compilation of possible sites followed by field survey to get a feel for the operation of the intersection.
3. compilation of detailed site, traffic and accident data from historical records and site surveys.
4. the detailed analyses of the data including testing the performance of the model developed by Hughes (1991) for WA using data for South Australia sites, and refining the WA models based on the WA methodology or overseas experience, or using new approaches developed as part of the study.

2.0 REVIEW OF PAST STUDIES

2.1 PREVIOUS WORK

A review of the results on work done so far on the relationship between accidents and traffic flow at intersections have not been consistent. The first authoritative work done in this area was by Tanner (1953). He investigated the relationship between traffic flow and accidents at three way rural roads, by considering the relationship between crash occurrence (A) and the two conflicting turning flows q_1 and q_2 of the form:

$$A \;\alpha\; q_1^a q_2^b$$

Tanner estimated with different values for the constants a and b, but found them not to be significantly different statistically from 0.5 and so concluded that accidents were related to the square root of the product of the two conflicting flows. This implied that road crashes increases directly with the square root of the product of the two conflicting flows. This relation has been applied and confirmed by several others. Brown (1982) for 4 leg intersections using an approach based on conflicting traffic movements, and Bennett (1966) for heavily-trafficked rural three-way junctions. Raff (1953) related accidents to the sum of the entering flows, while McDonald (1953) considered accidents and the minor cross road traffic volumes. They all developed simple models, but quite different in nature. Chapman (1973) also discussed the choice of three possible exposure measures for intersection, while Council, Stewart, Reinfurt and Hunter, (1983) and Council, Stewart, and Rodgman (1987) developed different exposure measures depending on the type of accidents under consideration. The theory behind the derivation of their exposure measures are tangible but due to the large variations in some of the parameters considered and the complex nature of the recommended exposure measures, their use in practise may be limited.

The flow-only exposure measures suggested will probably not be appropriate in different environment where signal operations and driver behaviour are different. McGuigan (1981) in his search for an appropriate procedure for ranking hazardous locations found crash rate to be directly related to the sum of traffic through the intersection. Hall (1986) conducted a detailed study of accidents at signalised intersections. He used both the total sum of pedestrian and vehicular flow or the cross product of the conflicting flow depending on the type of crashes being modelled. His relationship included a large number of site and control features and a function of traffic flow. His results were all highly significant but he found that the simpler models were more promising than the complex ones. Hughes (1991) found a simple linear relationship to be the best predictor of accidents for the whole intersection. He also developed models for each of the main crash types using multiple linear regression techniques which included other traffic control and site factors. All these studies have demonstrated that road crashes are in some way related to the traffic using the road. The variations in the form of the flow function found to be related to crashes in the above studies can be the result of the way the research was conducted but point to one main thing. Road crash relationships with traffic flow vary from one place to another. This is so due the fact that road crashes occur as a result of a whole range of complex interaction between the road and its environment, the vehicle and the human element prior to the time of impact. Whereas it is possible for the road environment and the vehicle to be similar from place to place, human behaviour varies from place to place and from one person to another.

2.2 THE BASIC CONCEPT

The basic underlying theory behind the development of most of these models is based on the assumption that the expected number of accidents for a given site is a function of exposure and accident propensity. That is, the expected number of accidents, E(A) is given by the relation

$$E(A) = f()g()$$

where $f()$ is defined as the exposure variable and $g()$ as the propensity

Exposure is defined as the number of opportunities for accidents of a given type in a given area. Propensity is defined as the conditional probability that an accident occurs given the opportunity for one. Thus the expected number of accidents is defined as the product of exposure and propensity. While there are excellent references (Council et al, 1983, 1987) for the appropriate exposure measures for various accident types, the same cannot be said of propensity. The review of 30 studies by Satterthwaite (1981) found inconsistency in about half of them. In general the propensity for accidents at a given location depends on traffic volume and a number of driver, vehicle and environmental factors including: traffic control devices, light and weather conditions, road surface conditions, road design standard, and vehicle and driver performance.

The interactions between road crashes and traffic can be studied in two ways. The first uses a function of flows using the intersection as the exposure and compares the observed crashes with this exposure. The other approach uses empirical accident and flow data for many locations to find a relationship between crashes and traffic flow. This approach assumes that the risk at each location is the same. These approaches plus actual vehicular movement observations have led to four exposure measures being suggested for crashes at intersections: the total traffic using the intersection, product of the cross flows on conflicting paths, square root of product of the cross flows and the observed number of conflicts at a location (Chapman, 1973).

3.0 METHODOLOGY

3.1 SITE SELECTION

Rarely do local and state authorities collect traffic flow data on minor junctions which are either uncontrolled or controlled by stop and yield signs except when the junction is known to be unsafe and some form of action is required to ratify the situation. Hence traffic flow data rarely exist for these intersections. As a result the present study will be limited to intersections controlled by either signals or roundabout. These intersections tend to be the more important ones in an urban road network, and most road crashes at intersections occurred at these intersections

3.1.1 Signalised intersections

In Adelaide, signalised intersections are controlled by the Department of Transport (DRT) or the Adelaide City Council, depending on the intersection location. Adelaide City Council is in charge of the intersections in the City of Adelaide (comprising North Adelaide and the Central Business District (CBD)) while the DRT is in charge of the rest of the metropolitan area. Due to the large amount of pedestrian activity in the CBD area, the signals there have been designed to favour pedestrian movements even though exclusive pedestrian phases are not provided. This result of this is that most signals operate on simple two phase cycle with the exception of signals on the arterial streets bounding the CBD area. It was decided to select sites from these two areas. Sites to be included in the study were designed to satisfy the following conditions over the four year study period from 1988 to 1991:

1 the availability of comprehensive traffic flow data and accident data
2 there should be no major geometric changes (eg addition of lanes or turn pockets)
3 no appreciable signal phasing modifications (eg provision of green arrows, changes in signal timings etc.) and
4 no appreciable traffic volume changes should have occurred such as those due to the construction or extension of a freeway or closure of a nearby street or any other large scale road project.

All signalised intersections that satisfied the above conditions were selected with the help of the Traffic Planning and Traffic Signals Sections of the DRT and the Adelaide City Council. The selected intersections were not determined by accident history or reputation but rather by their eligibility on the basis of the four conditions described above. This eliminated any intentional biases in the selection on the part of the research team. In all, 62 intersections were selected from the CBD and 53 from the Adelaide metropolitan area outside the CBD area, giving an overall total of 115 signalised intersections. Fewer sites were selected from the DRT traffic control area than Adelaide City Council area, due the many changes that have been taking place at DRT-controlled intersections over recent years in response to general traffic growth in the metropolitan area. Traffic volumes in the CBD area have remained roughly the same over several years.

3.1.2 Roundabouts

Roundabouts in Adelaide are either controlled by the DRT or the local council depending on its location. Roundabouts on main arterial roads come under the control of the DRT and those on local streets are controlled by the local council concerned. Sites were to be selected from both depending on the availability of traffic flow data. It was found that the local councils seldom collect any comprehensive flow data once the roundabouts are in place. Even when they do what is collected concerns flow on only the main street, which were considered not appropriate for this study. With the DRT, traffic counts data were available for only those roundabouts known to be problematic in terms of high crash occurrences. As a result traffic flow data were available for only 10 roundabouts in the metropolitan area. This sample size was too small for developing appropriate models for predicting crashes at such locations. Moreover since these roundabouts are known to have exceptionally high crash rates their use in model development would result in models inappropriate for use in other areas. Due to this consideration only a comparative study of the crash situation at these locations was undertaken. Summary crash statistics were produced and these compared with signalised intersections with similar flow characteristics.

3.2 DATA COLLECTION

3.2.1 Road crash data

The records of all road crashes occurring at the selected intersections were obtained from the Office of Road Safety for the four years 1988 to 1991. The information recorded for each crash included the following

- accident report number
- location of crash
- number of casualties
- date of occurrence of collision (day, month and year)
- time of accident (hours and minutes)
- day of week
- intersection type
- crash type
- crash severity
- traffic control type
- type of vehicle manoeuvre
- direction of vehicle travel
- types of vehicle unit involved

Each accident was assigned a detailed accident location type code according to the direction and movement of vehicles involved so as to associate each crash with the various relevant approaches of the intersection. This process is based on the crash type, direction of travel and vehicle manoeuvre. The coding method employed is the one used by SA which is slightly different from the road user movement (RUM) used in Victoria and New South Wales. For rear end and side swipe collisions, the crash was associated with the intersection approach on which the vehicles were travelling. For right angle collisions the crash was associated with the approach whose stop line is nearest to the point of impact, while for right turn collisions, the crash was associated with the approach from which the turning vehicle approached the intersection. For some accident records this process was impossible, due to coding errors or omissions of information. In these cases it was required to examine the original police accident report form to obtain the required information. Even then some 18 crashes could not be associated with any approach due to insufficient information from the report forms. These were thus excluded from the analysis.

3.2.2 Traffic Flow data

Turning flow counts were considered the most suitable traffic flow data for the study. The traffic flow data required for the study were obtained from two sources: Adelaide City Council and DRT. Traffic flow data collected by the DRT comprise 11 hour turning classification counts supplemented by 24 hour automatic counts on selected arterial roads. Flow counts for the selected sites for the years 1988 to 1991 were collected where they were available. There was at least one year of data for the sites selected. From the automatic counts and the 11 hour turning count the department has developed factors for converting the 11 hour counts to annual average daily traffic (AADT) flows depending the site location, day and month of count.

The Adelaide City Council collects the morning and evening peak hour turning flows at most of its signalised intersections at least once a year. These counts are supplemented by 24 hour automatic counts. Conversion factors for converting the peak hour flows to AADT have been developed using the 24 hour automatic counts. Separate conversion factors are produced for the morning and evening peak hour flows for each day of the week. Some of these factors have been derived by the Adelaide City Council whilst those for other intersections for which these conversion factors were not available have been determined as part of this project. These factors are shown for each approach of the selected intersections in Appendix A.

These conversion factors were used to convert the peak and 11 hour turning flows to AADT and then to annual traffic flow in million vehicles per annum (Mvpa) by multiplying by 365. Subsequent years with no actual count data were estimated from calculated annual variation factors (DRT, 1993).

3.2.3 Traffic control and location data

For each signalised intersection the following details were collected:

- signal phasing diagrams;
- whether coordinated with adjacent signals or not;
- fixed time or traffic actuated:
- cycle length and plan schedules;
- intersection geometry;
- number of intersecting legs;
- number and width of lanes.

This information was obtained from detailed design maps of these signalised intersections obtained from the Traffic signal sections of the DRT and Adelaide City Council. For the roundabouts, information collected included

- number of lanes at the approach and around the circle;
- circle inner and outer diameters, and
- speed limit.

These information were collected for the 10 roundabouts where traffic flow data were available.

3.3 DATABASE DESIGN

Three data types relating to the intersections were being used (traffic control and location data, traffic flow and accident data). The database design involved the storage of the above data sets and the subsequent manipulation to provide the summary statistics for each intersection or approach of the intersection required for the model verification and development. Geographic Information Systems (GIS) is an excellent technology for managing utilities, transport facilities, and other forms of spatial data. It is an ideal tool for manipulating, analysing and visual display of spatial data. It simplifies the extraction and presentation of inventory data, thereby providing a higher degree of user friendliness, better access to data and has the ability to integrate data from a wide variety of sources from which a new set of data can be developed for other purposes. It was therefore decided to store the above data sets in a GIS environment. The GIS software used for the purpose is the PC ARC/INFO package, a product from Environmental Systems Research Institute Inc, Redlands, USA.

Digital coordinates of Adelaide Street Network in ARC/INFO format were available from the GIS. From these coordinates, the coordinates of the selected intersections were obtained and used in the GIS to create a map layer termed coverage in the ARC/INFO terminology. Each intersection was assigned a unique identification number to be used in linking the various data associated with each intersection. The traffic flow data and site location data for each intersection were input into the Excel spreadsheet package and stored in dBase format. Each record contains the unique intersection identification number as described above. Similarly, the accident data were imported into Excel and stored in dBase format. These data files were then imported into ARC/INFO Tables (a relational database system) without any further conversion. The schema of the accident database remained the same after the conversion except that it was now in ARC/INFO format. In the GIS each accident record was assigned the intersection identification number of the intersection at which it occurred.

The GIS data integration capabilities were employed to join these data files, using the intersection identification number, as the joining item to produce summary information such as annual accidents recorded, annual traffic flow, signal cycle length, accident statistics by type etc for each intersection and intersection approach. The summary statistics were output into a file for use in the modelling process. Other uses of the GIS database developed include visual display of the intersections and its associated attributes, management and monitoring of the signal facilities, and identification of hazardous locations. Summary tables can be produced that combine accident and traffic flow, accident rates can be calculated and detailed analysis of accidents is possible. Pinpointing problem spots by displaying sites with high accident rates, accidents frequency or based on any criteria, intersections operating over capacity can all be done at ease.

4.0 ANALYSIS OF ROAD CRASHES

4.1 INTRODUCTION

The objective of the analysis in this section is to compare the road crashes and traffic flow situation of the selected signalised intersections with those of WA as reported by Hughes (1990), and also to ascertain if there are differences in road crashes at signalised intersection in the CBD and those outside the CBD area. This comparison is necessary since the operation of the signals in the respective jurisdictions is quite different as already discussed. The crash statistics at roundabouts for which traffic flow data were available are also produced and compared with those of signalised intersections of comparable flows.

4.2 SIGNALISED INTERSECTIONS

Table I shows the summary statistics for the intersections for the four year period providing a comparison between crashes in the CBD and the suburban areas. This is for the 6391 accidents for the 115 signalised intersections selected obtained from the office of Road Safety compared with a comparable four years of data from WA. The crashes for the period were widely distributed around the mean and were slightly skewed positively compared to the mean.

Table I: Signalised intersection accident summary statistics

	South Australia (1988-91)			
	CBD	**Suburban**	**All sites**	**WA(1986-89)**
No. of Intersections	47	68	115	121
Total crashes	2388	4003	6391	7815
Mean	50.81	58.87	55.57	64.6
Median	40	45	43	54
Standard Deviation	36.48	45.03	41.77	39.4
Standard Error	5.32	5.46	3.39	3.58
Kurtosis	2.24	3.31	3.32	3.82
Skewness	1.47	1.75	1.71	1.19
Lower quartile	27	26	27	39
Upper quartile	63	73	73	80
Minimum	5	10	5	8
Maximum	167	237	237	190

More detailed analysis showed that the major types of crash at signalised intersections were rear end, side swipe, right angle and right turn collisions. These types make up more than ninety percent of the total crashes. Comparable data for WA (Hughes, 1991) as shown in Table II. which compares well with other areas (Hughes, 1991) shows a similar breakdown (see Table II). Rear end collisions alone accounted for more than 50 percent of the total accidents (see Table

II) and 44 percent of casualties. Most of collisions were property damage only type (approximately 85%) as shown in Table III. Further analysis showed that half of the fatalities involved right turning vehicles while the other half involved vehicles hitting fixed objects.

Table II: Intersection crash statistics by type of collision.

Type of Accident (%)	CBD	Suburban	SA data	WA data
Rear end	43.59	57.81	52.50	47.30
Side swipe	10.34	9.29	9.69	9.40
Right angle	17.50	12.09	14.11	14.70
Right turn	23.33	15.16	18.21	17.90
Others	5.24	5.65	5.49	10.70
Total	100.00	100.00	100.00	100.00

Table III: Intersection crash statistics by accident severity

Accident severity (%)	CBD	Suburban	SA data	WA data
Property damage only	82.37	83.36	82.99	78.00
Injury	17.59	16.51	16.92	21.90
Fatal	0.04	0.12	0.09	0.15

Table IV: Intersection crash summary statistics by type (4 years total)

	Rear end crashes		Side swipe crashes		Right angle crashes		Right turn crashes	
Parameters	**SA data**	**WA data**	**SA data**	**WA data**	**SA data**	**WA data**	**SA data**	**WA data**
No. of Intersections	115	121	115	121	115	121	115	121
No. of Approaches	422	421	422	421	383	369	339	299
Total crashes	3350	3699	615	732	883	1146	1149	1398
Mean	7.94	8.77	1.48	1.74	2.31	3.10	3.39	4.68
Median	4	6	1	1	2	2	2	3
Standard Deviation	9.59	11.81	3.52	5.01	2.32	4.57	4.45	4.86
Kurtosis	7.74	30.12	196.07	65.18	2.41	85.77	16.78	9.67
Skewness	2.29	4.36	12.08	7.31	1.53	7.34	3.33	2.01
Lower quartile	1	2	0	0	1	1	1	1
Upper quartile	12	11	2	2	3	4	5	7
Minimum	0	0	0	0	0	0	0	0
Maximum	70	114	61	53	12	63	35	35

It is seen that crashes were less frequent in the CBD than elsewhere (see Tables I and II). This may be due to drivers being more careful in the CBD and partly because drivers are familiar with the complex land use activities and the high pedestrian involvement and possibly due to lower vehicular speeds. Crash severities are, however, identical in the two areas. The CBD has a higher proportion of right turn accidents due probably to the fact that most of the signals operate the permissive or filter form of right turning phase. That is the right turning vehicles have no exclusive green phase and are required to move with the opposing flow through an acceptable gap. As noted in section 3.1.1, the CBD signals have been designed as simple two-phase systems to maximise pedestrian crossing opportunities. Separate turn phases have therefore been deliberately excluded at intersections in the Adelaide CBD. The proportion of rear end accidents is also lower due probably to reduced vehicular speeds and extra care taken by drivers as a result of the many human interaction and the land use activities in the CBD at those intersections.

Comparison of the SA road crashes with that of WA showed that signalised intersections in SA were safer that those in WA, as indicated by the mean number of crashes per intersection, the crash rates in million vehicles, and the severities of these crashes (see Tables III to V) assuming the crash rates to be comparable for the two periods being compared. It should however be borne in mind that the high proportion of property damage only crashes in SA may be due to the fact that in that state, until recently all crashes were supposed to be reported to the Police. Since the models obtained using the WA data are linear one would expect an increase in the mean number of accidents to increase with an increase in entering traffic flow.

Table V: Comparison of SA and WA crash rates at signalised intersections

	No of crashes (4yrs total)		Mean annual traffic(Mvpa)		Crash rate (crash/mil.-veh)	
Parameters	**SA(1988-91)**	**WA(1986-89)**	**SA(1988-91)**	**WA(1986-89)**	**SA(1988-91)**	**WA(1986-89)**
No. of Intersections	115	121	115	121	115	121
Mean	55.57	64.6	14.499	11.164	0.930	1.407
Median	43	54	13.411	11.117	0.818	1.233
Standard Deviation	41.77	39.4	5.762	3.562	0.484	0.646
Standard Error	3 39	3.58	0.537	0.324	0.045	0.059
Kurtosis	3.32	3.82	1.511	-0.165	-0.378	1.849
Skewness	1.71	1.19	1.008	0.298	0.697	1.291
Lower quartile	27	39	10.330	8.645	0.559	0.949
Upper quartile	73	80	17.489	13.291	1.263	1.760
Minimum	5	8	4.616	3.444	0.142	0.400
Maximum	237	190	34.781	20.766	2.264	3.792

4.3 ROUNDABOUTS

As seen from Table VI the mean number of crashes at the selected roundabouts was about 52 for the four years (that is 13 crashes per roundabout per year). It should be noted that the high mean value is the result of high crash frequency recorded at three of the roundabouts (see Table VII). The distribution of the crashes is positively skewed and widely spread around the mean. The most frequent type of crashes are rear end, side swipe and right angle collisions(see Table VIII). Approaching crashes(rear end and side swipe crashes) account for over 65 percent of all collisions at the roundabouts. Only about ten percent of these crashes resulted in injury involving

Table VI: Crashes statistics at roundabouts and signalised intersections

Parameters	No of crashes		Flow (Mvpa)		Crash rate	
	Round-abouts	Signals	Round-abouts	Signals	Round-abouts	Signals
Number of observation	10	48	10	48	10	48
Total	436	1840	311.21	531.00	12.9	42.59
42	43.60	38.33	6.78	11.08	1.29	0.89
Standard Error	17.30	2.90	0.94	0.39	0.28	0.06
Median	28.00	34.00	6.51	11.24	0.90	0.84
Standard Deviation	48.93	20.12	2.96	2.70	0.89	0.44
Kurtosis	1.16	1.26	0.93	-0.26	-0.59	-0.29
Skewness	1.33	1.13	0.93	-0.68	0.91	0.81
Minimum	5.00	13.00	3.14	4.62	0.40	0.22
Maximum	150.00	100.00	13.01	14.93	2.88	1.85
Upper quartiles	94.00	51.00	8.84	13.24	1.95	1.00
Lower quartiles	22.00	22.00	4.52	9.28	0.55	0.53

Table VII: Comparison of crashes at roundabouts and signalised intersections

Flow range (Mvpa)	Roundabouts*	Signals*
0.0 - 5.0	7.33 (3)	18.00 (1)
5.0 - 7.5	25.25 (4)	23.25 (4)
7.5 - 10.0	81.50 (2)	37.00 (9)
10.0 - 12.5	-	41.64 (14)
12.5 - 15.0	150 (1)	40.65 (20)

* Note: figures in brackets indicate number of observations in the group

Table VIII: Crash variations by type

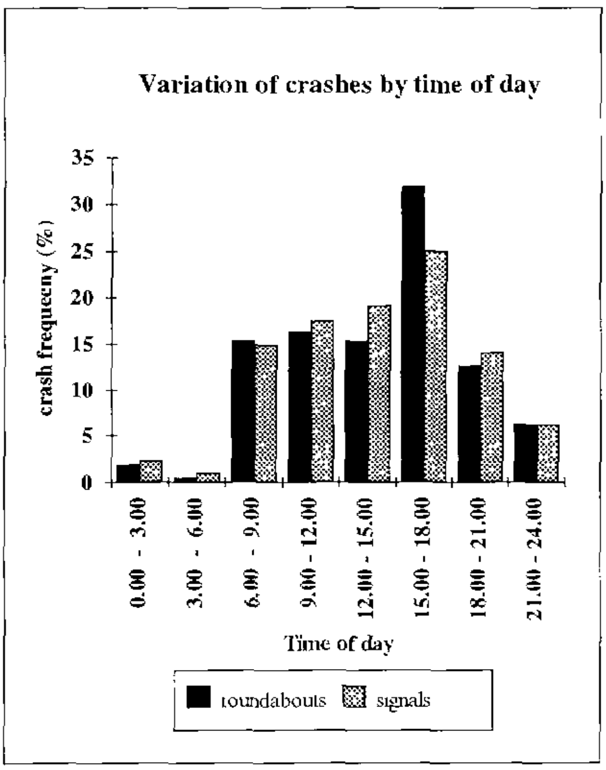
	Roundabouts		Signals	
Type of crash	**crashes(%)**	**casualty(%)**	**crashes(%)**	**casualty(%)**
Rear end	36.47	39.68	42.39	25.27
Side swipe	30.38	7.94	6.85	3.27
Right angle	22.02	19.05	19.57	29.41
Right turn	3.44	7.49	25.33	31.37
Hit fixed object	4.82	17.46	2.55	3.92
Others	2.87	8.38	3.31	6.76

63 casualties. The rest resulted in property damage only (see Table IX). Hence as far as crash severity was concerned these roundabouts may still be regarded as safe. There is a high proportion of casualties resulting from crashes where the vehicle collided with fixed objects, as seen from Table VIII.

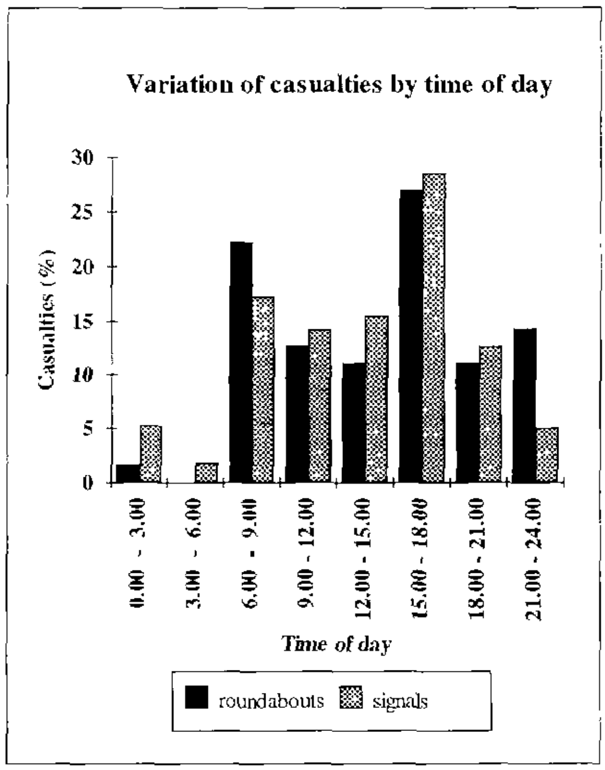
Table IX: Crash variations by severity

Accident severity (%)	Roundabouts	Signals
Property damage only	88.53	80.93
Injury	11.47	19.02
Fatal	0.00	0.05

Further analysis of the data (Figure 1) indicated that most crashes and injuries occurred during the day time period with about a third of these occurring between three o'clock and six o'clock in the evening, coinciding with the evening peak periods. From Figure 2, it is observed that the probability of a crash is almost equal on any day during the week. However it is also observed that most injuries occurred from Monday to Thursday with Wednesday registering the highest number of casualties. Figure 3 indicates that most collisions occurred in the months of June and July possibly due to the more frequent occurrence of wet weather and shorter daylight hours in these months.

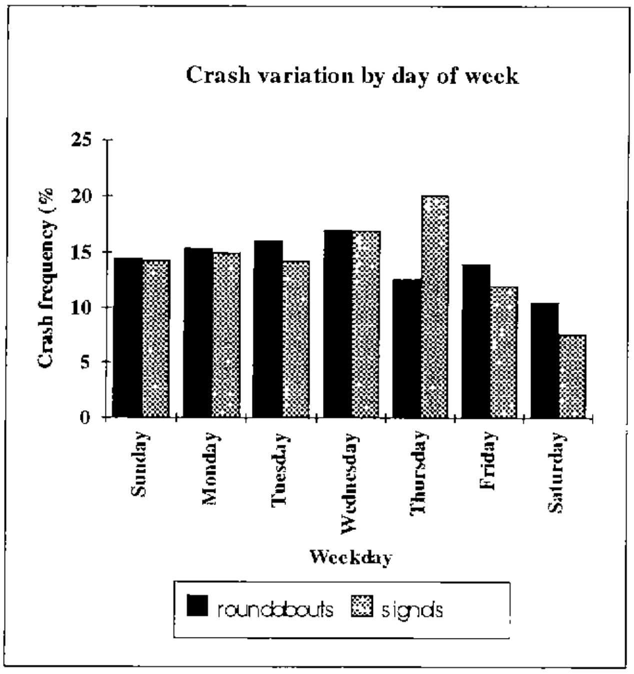


a: Crash proportions

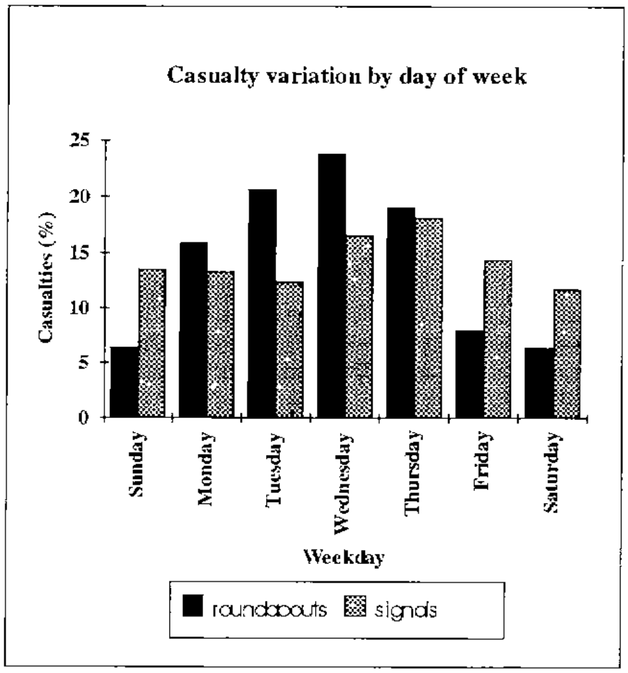


b: Casualty proportions

Figure 1: Variation of crashes by time of day



a: Crash proportions



b: Casualty proportions

Figure 2: Variation of crashes by day of week

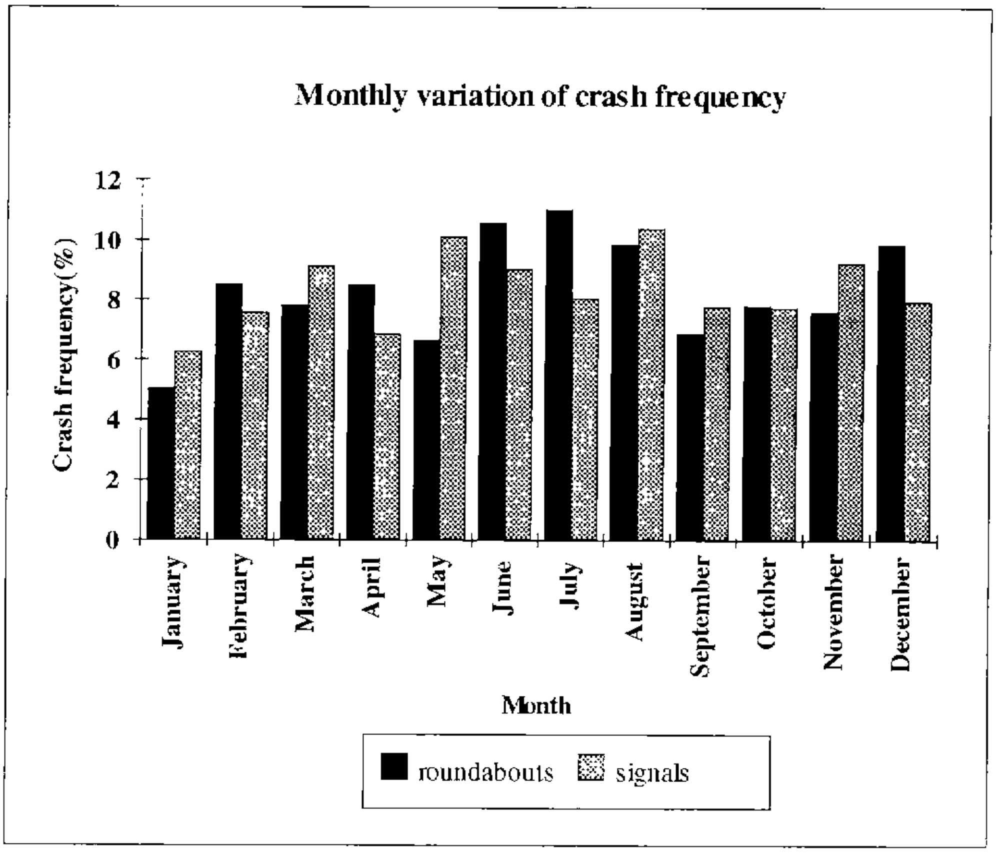


Figure 3: Variation of crashes by month

4.4 COMPARISON OF CRASHES AT ROUNDABOUTS AND SIGNALISED INTERSECTIONS

Flow and crash statistics for signalised intersections with traffic flow within the range of the selected roundabouts were obtained for comparison with those of the roundabouts. All the signalised intersections included in this sample had four approaches, corresponding with those of the roundabouts. Tables VI to IX and Figures 1 to 3 give the results obtained for the various crash statistics between the two intersection types. It was found that over the whole range of flow considered, there were more crashes at the roundabouts than the signalised intersections as indicated by the mean number of crashes and mean crash rate (see Table VI). Disaggregating the crash statistics into traffic flow ranges showed that the collision situation at roundabouts compares favourably with the signalised ones if not safer at low traffic flows(see Table VII). At higher flows (above about 7.5 million vehicles per annum) the roundabouts tended to be more dangerous than signalised intersections carrying the same amount of traffic as seen in Table VII. In the highest flow range there were twenty signalised intersections; the maximum number of crashes per intersection was 100 which was 33 percent less than that at the single roundabout with the highest crash record. Comparison of the collisions by type indicate rear end, side swipe, right angle and right turn collisions to be the main crash types at both intersection types. However, the proportion of each type is different at the two intersection types (see Table VIII). For example, there were a higher proportion of side swipe crashes at roundabouts (38.4%) than at signalised intersections (6.9%). There are fewer right turn crashes at roundabouts (3.4%) than at signalised intersections (25.3%). This is expected judging from the definition of a crash being termed as a right turn collision. Roundabouts also recorded slightly fewer proportion of rear end collisions but higher right angle collisions than the signalised intersections.

4.5 VALIDATION OF HUGHES MODELS USING SA DATA SET

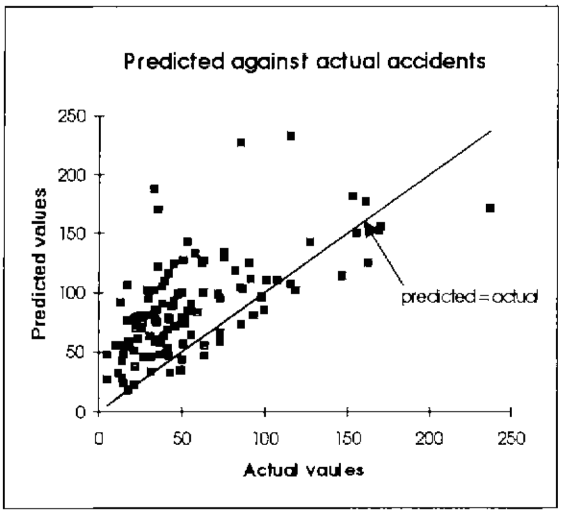
This section deals with validating Hughes model using an independent data set from SA to determining its applicability to other areas. The approach used involved using the collected traffic data to predict the crash occurrences using Hughes regression models. These predicted values are then compared with the actual number of crashes recorded at each location. The Wilcoxon-sign non-parametric test is then used to test the hypothesis of no difference between the two values.

4.5.1 Total Intersection accidents

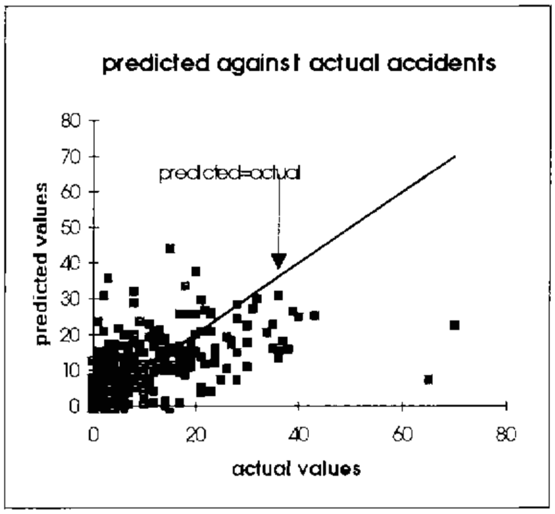
Figure 4 shows the result of applying the SA sample data to Hughes' model. Hughes model for the total number of crashes at a signalised intersection is given by:

$$E(A) = 7.122V - 14.922$$

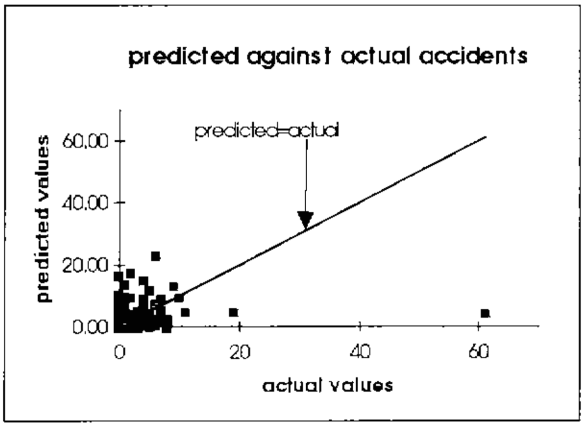
where $E(A)$ is the expected number of crashes for a four year period and
V is the exposure measure given by the total entry traffic flow in million vehicles per annum (Mvpa)



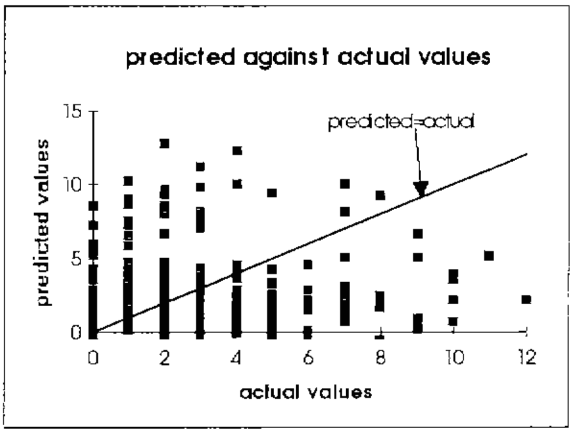
a. Total intersection accidents



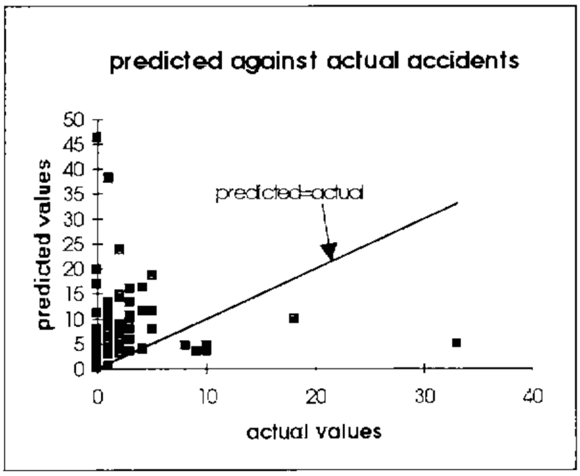
b. Rear end accidents



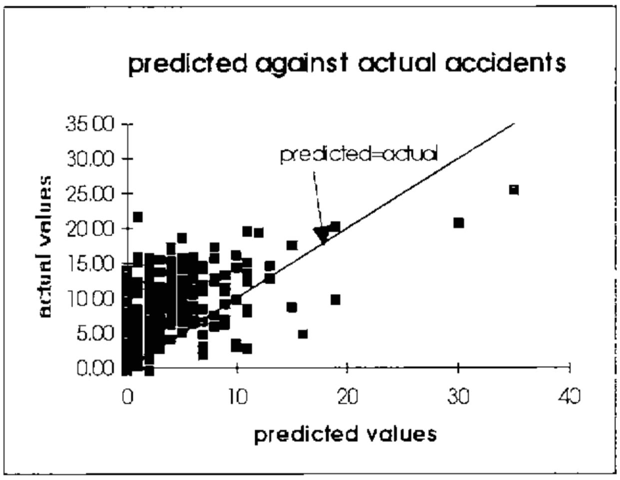
c. Side swipe accidents



d. Right angle accidents



e. Right turn accidents (protected phase)



f. Right turn accidents (protected/filter)

Figure 4: A plot of predicted accidents against actual accidents recorded (SA, 1988-91).

Using the above model and SA traffic flow data predicted number of crashes were calculated and plotted against the actual number of intersections crashes recorded as shown in Figure 4a above. The model predicted the actual crashes quite well although it had a tendency to overestimate in a majority of the cases. Table X shows a comparison between the actual and predicted crashes. From this table and Figure 4a visual inspection indicated a poor prediction capability. This was confirmed by a test of the hypothesis that there was no difference between the predicted and actual crashes recorded using the Wilcoxon test. The hypothesis was rejected at the five percent level of significance (ie the result was that there was less than five percent probability of the observed difference occurring by chance) indicating that an improved model should be sought.

4.5.2 Approach based models for the main crash types

Similarly the predicted values for each of the models developed for the main types of crashes were calculated from the WA models. A plot of these predicted values against the actual number of crashes recorded are shown in Figures 4b to 4f. The predicted values are particularly bad for right angle collisions. The inherent difficulty in developing a model for right angle crashes will be discussed in more detail later in this report. In all cases, a test of the hypothesis that there is no difference between the predicted and actual crashes recorded using the Wilcoxon test was rejected at the 5 percent level of significance, indicating that the models developed by Hughes using WA data are not directly applicable to SA intersections and that improved models should be sought.

4.5.3 Overall assessment

In summary, it can be concluded that the models developed by Hughes for WA cannot be directly transferred to SA conditions. the lack of predictive ability applies to models for total intersection crashes and to models for the individual crash types.

Table X: Validation of Hughes model for total intersection accidents using SA data

Junction ID	Actual crashes	predicted crashes	difference	percentage difference	Junction ID	Actual crashes	Predicted crashes	Difference	Percentage difference
1	60	84	24	39.37	59	32	33	1	3.21
2	128	142	14	11.04	60	26	74	48	185.75
3	82	119	37	44.69	61	25	81	56	222.04
4	46	72	26	56.58	62	5	48	43	856.31
5	22	77	55	252.06	63	18	18	0	-0.27
6	41	69	28	67.69	64	86	73	-13	-15.17
7	85	104	19	22.87	65	237	171	-66	-27.67
8	33	102	69	207.59	66	50	100	50	99.88
9	42	79	37	88.15	67	116	107	-9	-7.79
10	62	125	63	100.96	68	45	90	45	99.85
11	42	116	74	176.66	69	98	97	-1	-1.41
12	36	122	86	237.55	70	101	110	9	9.35
13	76	130	54	71.01	71	163	125	-38	-23.34
14	40	110	70	174.09	72	15	55	40	269.64
15	17	106	89	523.19	73	64	47	-17	-27.14
16	13	91	78	603.04	74	100	85	-15	-14.99
17	35	86	51	144.51	75	37	57	20	55.21
18	51	128	77	150.46	76	108	110	2	2.16
19	76	134	58	75.92	77	147	114	-33	-22.31
20	29	102	73	252.92	78	63	127	64	102.23
21	31	63	32	104.52	79	161	177	16	9.88
22	169	153	-16	-9.65	80	156	151	-5	-3.50
23	36	60	24	65.39	81	25	70	45	178.60
24	92	112	20	21.65	82	10	56	46	460.69
25	58	133	75	128.61	83	170	156	-14	-8.40
26	153	181	28	18.35	84	35	75	40	114.42
27	85	227	142	167.41	85	38	90	52	137.91
28	116	233	117	100.68	86	32	46	14	43.40
29	73	95	22	30.75	87	26	70	44	167.65
30	12	33	21	173.12	88	45	93	48	106.84
31	87	102	15	17.81	89	21	23	2	8.15
32	52	78	26	50.62	90	37	48	11	28.79
33	34	78	44	129.47	91	18	58	40	224.75
34	91	125	34	37.59	92	64	56	-8	-12.83
35	56	85	29	50.98	93	48	99	51	106.01
36	38	105	67	175.78	94	44	89	45	101.88
37	51	56	5	10.41	95	72	99	27	37.22
38	24	70	46	191.63	96	30	95	65	215.67
39	15	23	8	54.69	97	21	51	30	143.80
40	19	55	36	188.11	98	73	66	-7	-9.26
41	63	99	36	57.75	99	56	64	8	14.30
42	27	75	48	178.85	100	73	59	-14	-19.66
43	53	85	32	59.57	101	27	46	19	68.71
44	119	102	-17	-14.13	102	93	81	-12	-12.70
45	22	79	57	258.32	103	17	76	59	349.58
46	30	81	51	168.63	104	52	74	22	42.08
47	50	79	29	57.29	105	39	64	25	63.67
48	14	43	29	204.88	106	22	38	16	71.72
49	5	27	22	439.38	107	43	77	34	79.79
50	34	86	52	152.32	108	24	79	55	230.79
51	53	143	90	169.01	109	42	46	4	10.34
52	33	188	155	469.16	110	50	43	-7	-13.88
53	24	61	37	156.00	111	43	32	-11	-25.00
54	15	48	33	221.56	112	23	70	47	205.23
55	41	54	13	31.06	113	45	124	79	174.78
56	14	28	14	102.26	114	34	59	25	73.74
57	56	91	35	62.45	115	49	35	-14	-28.36
58	36	170	134	373.48					

5.0 MODEL DEVELOPMENT

5.1 INTRODUCTION

The inability of the models developed by Hughes using WA data to accurately predict road crashes in South Australia meant that the WA models had no general predictive capabilities for SA intersections and thus new set of models needed to be developed. Analysis was therefore undertaken to use the collected crashes and traffic flow data for SA to develop new models. These models were based on the same exposure measures using the traffic movements contributing to that type of crash and other functional forms of the traffic flow as deemed necessary by the use of regression methods.

5.1.1 Model form used

The regression models considered were of the forms

$$E(A) = \beta \ (V)^{\alpha} \ + K \text{ and} \quad (1)$$

$$E(A) = \beta(V)^{\alpha} + g(\mathbf{x}) + K \quad (2)$$

where

$E(A)$ is the estimated number of crashes for the period;
V is the exposure measure used based on the total traffic flow over the period and the geometry of the vehicle movement contributing to the type of accident in question;
$g(\mathbf{x})$ is a function made up of significant site and signals factors; and
β, α and K are regression parameters, which can assume any value including zero.

If the constant K is zero then β is equivalent to the crash rate defined as crash per unit exposure. In most cases the constant K was found to be statistically not different from zero implying zero crashes at zero flow as expected. Where it was different from zero the value was negative so that the theory of no crash at zero flow still held. If $E(A)$ and V span over the same time period, as was the case in this study, then β is a constant and represent the crash rate expressed in crashes per unit exposure expressed in million vehicles.

For road crashes which are discrete and non negative, it can be appropriate to use the logarithm transformation can be used to transform the data before regression. However, except for the total intersection crashes, in the case of the various crash types which are modelled on an approach basis, this transformation is not possible because some values of the dependent variable are zero. For each intersection, the total number of accidents recorded in the SA Office of Road Safety accident database for the four years (1988 to 1991) was used as an estimate of the dependent variable. The use of accident rate has been suggested as the preferred dependent variable as against the crash frequency [Council et al (1987), McGuigan (1981)]. This was investigated and all result found statistically insignificant, and so its use was not pursue any further. Table I shows summary accident statistics used compared with those from WA. The traffic volume used is the total vehicular flow through the intersection for the four year study period. The vehicular movement contributing to a particular accident type was used in developing the exposure measure for that particular accident type. Where the occurrence of an accident involved vehicles travelling in the same traffic stream (that is travelling in the same direction) the exposure was taken to be a function of the sum of flow. On the other hand, if it involved conflicting flows the functional form of the product of the conflicting flows was considered. The regression analysis was performed using the SPSS for Windows statistical package. The regression analysis was done in two stages. The first involved determining the best functional form of the traffic volume exposure measure using both linear and non linear regression methods based on equation 1. The second stage of the regression involved performing a stepwise multiple linear regression using the best exposure measure determined from stage one and the non flow variables described below. Variables are included in the final models if they are significant at the five percent level. Elimination and inclusion of the variable is done automatically by the program. Regression models are of associative in nature and do not necessarily imply causative effect. However, in this case where a wide range of site, signal and other explanatory factors are considered, and the selected intersection are all controlled by signals providing some form of statistical control provided a strong implication of some level of cause and effect. If there were any factor not considered it is expected that their effects would be minimal.

5.1.2 Intersection geometry and signal variables considered

Due to the variations in signal parameters between intersections and within the same intersections, the signal variables used in the modelling include number of signal phases (denoted by P) divided into two groups as follow: up to four phases and five or more phases, the type of right turn control and whether the signal is coordinated with adjacent ones or not as described below.

Right turn signal control: 1 - protected right turn phase
2 - filter right turn only
3 - permissive/protected right turn phase

Signal coordination: 0 - not coordinated
1 - coordinated

The intersection geometry variables considered included the following:

- number of approach legs;
- number of lanes at stop line;
- approach width;
- right turn lane usage;
- left turn lane usage; and
- whether left turn with care at any time sign exists.

The definition of item variables used in the regression are as follows. The definitions of most of the variables were the same as those used by Hughes. This was done to allow the use of the WA data to test the generality of the models developed using the SA data. However, some new variables had to be introduced and others had to be redefined.

A- Protected right turn phase only. Vehicles move only on a green arrow and have an exclusive right of way when the green arrow indication is on.
B- Filter right turn only. Vehicles are allowed to make a turn on green signal but must yield or give way to opposing traffic. Thus drivers must turn by selecting appropriate gaps.
C- No right turn sign displayed during certain times of the day especially peak hours. This sign prohibit right turning during the times displayed
D- Double left or right turn lanes provided
E- Shared right turn lane. This factor is included to test the effect of a shared right turn lane on road crashes
F- Type of right turn phasing employed defined as 1 for protected; 2 for filtered and 3 for both protected and permissive movement in operation.
G- more than three approach lanes at the stop line
H- one way approaches.
I- approaches with turn left with care at any time sign.
J- Left turn lane usage defined as 1 for shared and 0 for exclusive left turn lane This factor is included to test the effect of a shared left turn lane on road crashes
K- signal coordination
L- Number of approach lanes at the stop line.
N- approaches with more than one signal stage per cycle
M- three way junctions
CBD - Central Business District
P- intersections with more than four signal stages. All the intersections satisfying this condition are outside the CBD.
PED- intersections and approaches with an exclusive pedestrian phase. (there were only two such intersections).

Some of the factors are strongly related and as such their inclusion in the same model is inappropriate as it would degrade the reliability and the predictive power of the resulting model. Care was therefore taken to avoid such situations. It was found that the CBD factor was significant in most of the models, confirming the accidents statistics shown in Tables I and II. One reason for this may be due to the difference in signal operations, the land use activities and differences in driver behaviour between the two areas. This prompted the idea of developing separate models for the two areas for comparison purposes.

5.1.4 Definition of traffic movements used

The traffic movements used in the study are defined as shown in Figure 5. The total flows on the approaches are defined by:

For approach 1: $V1 = q1 + q2 + q3$

For approach 2: $V2 = q4 + q5 + q6$

For approach 3: $V3 = q7 + q8 + q9$

For approach 4: $V4 = q10 + q11 + q12$

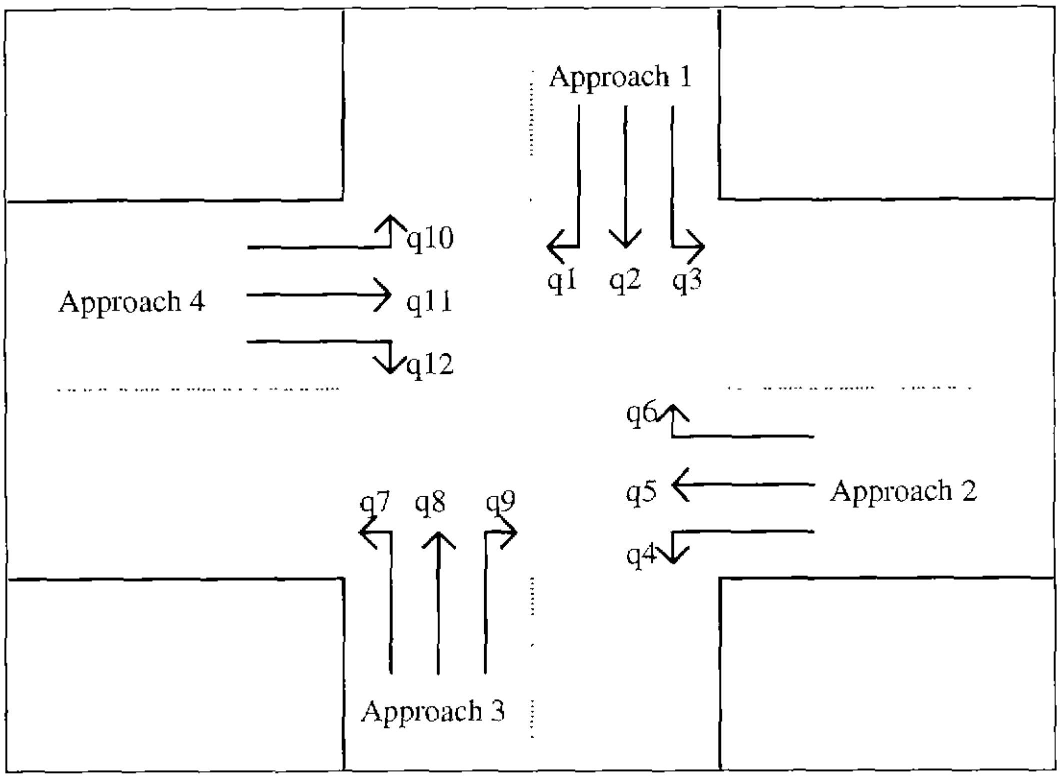


Figure 5: Definition of traffic movements.

5.2 TOTAL INTERSECTION CRASH MODELS

5.2.1 The regression models

The exposure measure considered involved various functional forms of traffic flow through the intersection. The actual exposure measures considered were the total sum of flow through the intersection and the cross product of flows on the intersecting approaches. The functional forms found to give reasonable results using both linear and non linear regression methods were the following:

1. Total sum of all traffic entering the intersection, given by:

$$Ep1 = V1 + V2 + V3 + V4$$

where V1, V2, V3 and V4 are as defined in Figure 2. For three leg intersections one of these variables is zero.

2. Exposure 2 (Ep2) is defined as the cross product of the sum of the two conflicting flows:
$$Ep2 = (V1+V3) \times (V2+V4)$$

3. Exposure 3 (Ep3) involved the square root of exposure 1 defined above, $Ep3= (Ep1)^{0.5}$.

4. Exposure 4 (Ep4) is the square root of exposure 2 defined above, $Ep4= (Ep2)^{0.5}$. The power of 0.5 was obtained by round off 0.499, which was the exact power obtained by performing a non linear regression on the data using exposure 2 (Ep2) above.

The regression equations obtained from the above exposure measures are shown in Table XI below. Exposure 4 provided the best model prediction parameters and so has been selected for further analysis by the introduction of the intersection geometry and traffic signal variables into the modelling process. The complete model then obtained is given by equation 5. The best models obtained for the CBD data and suburban data are given by equations 6 and 7 respectively. These models provide an improvement on the model parameters over that obtained derived from the full data set. with the R square value increasing to 53 and 73 percent for the CBD and suburban data respectively. When the signal and sites factors were added none proved significant. The main different between the two models is that the non CBD data has a regression coefficient almost twice that of the CBD data. Non of the site and signal factors proved significant when introduced.

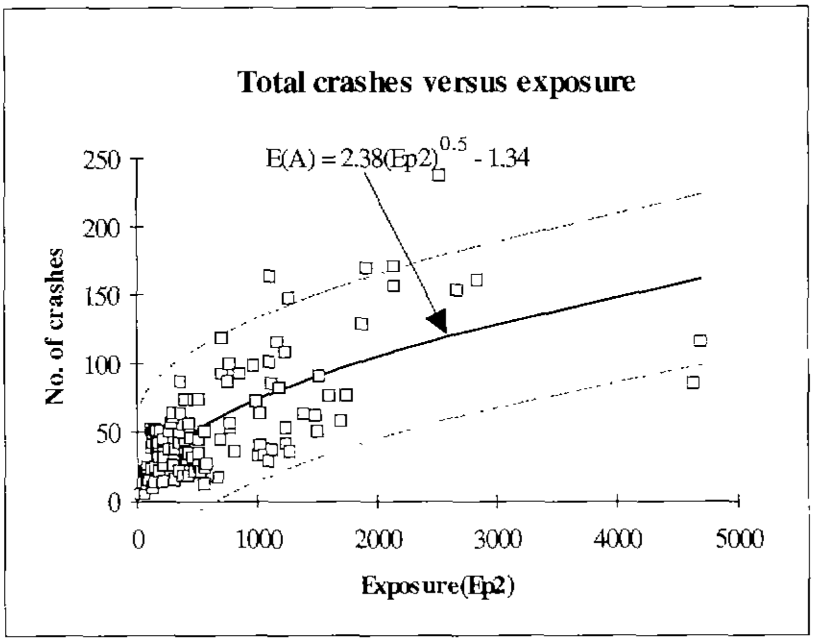
Table XI: Models of Total Intersection Accidents, SA 1988-91.

Region	Formula	R^2	Std.Error	F value	Prob.
All sites	1: $Acc = 1.15x(Ep1) - 11.39$	0.401	32.33	77.24	0.0000
All sites	2: $Acc = 0.03x(Ep2)+ 30.17$	0.440	31.26	90.58	0.0000
All sites	3: $Acc = 17.93x(Ep1)^{0.5} - 78.44$	0.394	32.52	75.11	0.0000
All sites	4: $Acc = 2.38x(Ep2)^{0.5} - 1.34$ **	0.493	29.74	111.88	0.0000
All sites	5: $Acc = 2.66x(Ep2)^{0.5}-24.57CBD+15.94P -1.57$	0.630	25.40	65.77	0.0000
CBD	6: $Acc = 1.99x(Ep2)^{0.5} - 6.84$	0.526	25.13	52.01	0.0000
Suburban	7: $Acc = 3.70x(Ep2)^{0.5} - 17.21$	0.734	23.20	186.39	0.0000

5.2.2 Discussion of models

A plot of this selected model (equation 4 from Table XI) is shown in Figure 6. This model explained about fifty percent the variations in the depended variable. The inclusion of the site factors resulted in a more complex formula but with improvements in the regression parameters

** Selected regression model for further analysis



——————— Regression line ------------ 95% confidence level

Figure 6: Total intersection accidents - Total entry traffic flow relationship (SA, 1988-91)

with the amount of variation being explained increasing to sixty-three percent. The only significant factors were the CBD factor and intersections with more than four signal phases (P). The first factor reduced the crash occurrence whilst the latter tended to increase it. The CBD factor thus indicate a reduction of crashes in the CBD area of about 24 crashes over the four year period.

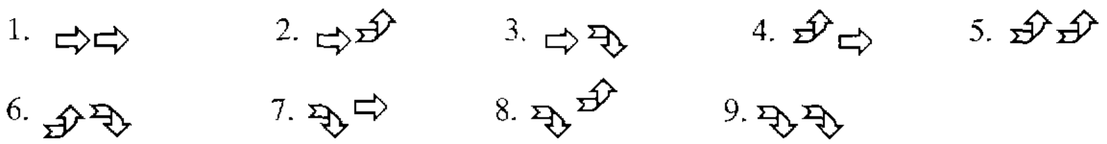
It should be noted than when the signal phases were grouped into different categories (2, 3, and 4 or more; up to three and more than three signal phases) the P factor was found to be insignificant. It became significant only for the classification of P described earlier (ie up to 4 or 5 or more phases). Extra signal phases are normally introduced to make it safer or easier to pass through the intersection especially for turning traffic (eg as right turn traffic increases exclusive right turn phases are introduced to cater for these movements). The coefficient of the P factor in the regression seem to suggest two things. It may be that having more than four signal phases has a net negative effect on reducing crashes at an intersection, possibly by reducing some type of collision (eg. right angle collisions) and increasing others (eg. rear end collisions). The second case may be that there is a point where increasing the signal phases contributes to increases in road crashes. This may be associated with the longer delays accompanying the increase in signal phases. Drivers tend to become frustrated and take more risks by running the red light or trying to cross as quickly as possible during the amber period even though the logical thing to do was to have stopped. Long cycle times associated with high number of phases might also cause drivers unfamiliar with the intersection to think that the signals are not working properly.

No site factor was found significant when the data was separated into CBD and non-CBD data indicating that the two factors coming into the model using all data set accounted for the variations in crashes between the CBD and the other areas. A test of the separate models and those obtained from using all data set indicated no difference at the 5% confidence level between with the complete model with the site factors. The exposure only model over-predicts for crashes in the CBD and under-predict for crashes in the wider metropolitan area.

5.3 REAR END COLLISION MODELS

5.3.1 Introduction

This type of collision occurs between vehicles travelling in the same direction and in the same lane on an approach. A crash involving any of the vehicular movement shown below is therefore classified as a rear end collision:



Rear end crashes are associated with the leg of the intersection on which the vehicles were travelling just before the crash. Rear end crashes form the single most frequently occurring crash type at signalised intersections. It is known that this crash type can increase at intersections when signals are installed (Homburger, Keefer and McGrath, 1982). The summary statistics for rear end crashes are shown in Tables II and IV. About half of the crashes occurring at the selected intersections were of this type, with an average of 7.94 crashes per intersection over the four years (that is about two crashes per intersection per year. The distribution was not normally distributed and was skewed positively.

5.3.2 The regression models

Two type of models were developed. One considered the crashes on an approach by approach basis while the other considered the intersection as a whole

a. Approach based models

The exposure measure considered was a functional form of the sum of flow using the approach in question (ie for approach 1 the first exposure measure (Ep5) is given by the sum of all traffic using approach 1).

$$Ep5 = V1 = q1 + q2 + q3$$

The best regression model obtained was the simple linear form indicating that rear end collision type increases with an increase in the total approach flows as seen from equation 1 of Table XV.

This model was highly significant, however the variation explained is low as seen from the value of the correlation coefficient (R squared). The introduction of the site variables gave equation 1a. The factors found to be significant included approaches with exclusive right turn phase (A), double turning lanes (D), no right turn sign during certain times of the day (C), more than 3 approach lanes (G), turn left at any time with care sign (I) and the CBD factor. With the exception of the CBD factor all the other factors tended to increase rear end collisions. Approaches in the CBD tended to have slightly reduced frequencies of rear end collisions following the same trend as the total intersection crashes.

Equations 2 and 3 in Table XII are the respective models obtained using the CBD data and suburban data only. Inclusion of the site factors gave equations 2a and 3a respectively. For the CBD data site factors found to be significant included approaches with double turning lanes (D), no right turn sign during certain times of the day (C), turn left at any time with care sign (I) and approaches with more than one signal phase per cycle. Outside the CBD area the only significant factors were turn left at any time with care sign (I) and the number of lanes (L).

Table XII: Approach based models for rear end collisions

Region	Model Equations	R^2	Std.error	F value	Prob.
All sites	1. RE = 0.455x(Ep5) + 0.74	0.216	8.49	117.10	0.0000
All sites	1a. RE = 0.36(Ep5)+2.19A+7.23C+5.1D+2G -2.7CBD +6.97I-1.17	0.452	7.10	50.64	0.0000
CBD	2.. RE = 0.408x(Ep5) - 1.28	0.216	8.49	117.10	0.0000
CBD	2a. RE = 0.208x(Ep5)+8.13C+10.1D +8.78I +5.62N-0.20	0.463	6.12	31.38	0.0000
Suburban	3. RE = 0.579x(Ep5) + 1.01	0.262	8.72	87.74	0.0000
Suburban	3a. RE = 0.396x(Ep5) +7.75I +2.98L - 7.07	0.472	7.38	73.62	0.0000

b. Model for whole intersection

The exposure measure considered was the total sum of flow entering the intersection (EP1), that is summing the exposure measure on each approach together (Ep1 = V1+V2+V3+V4). The regression equation obtained was given by:

RE = 0.781xEp1 - 16.11

having regression parameters of

R square = 0.351
Std. error = 24.28
F value =62.67
Probability=0.0000

When the intersection site factors were introduced the CBD factor and intersections with more than four phasings were found to be highly significant, following the same trend as model for all crashes for the whole intersections. This is no surprise since rear end collisions make up the bulk of all the intersection collisions. The relationship obtained is given below:

RE = 0.86xEp1 - 16.72CBD + 18.68P -17.94

This model was also highly significant with regression parameters of

R square = 0.544
Std. error = 20.35
F value =46.29
Probability=0.0000

The model obtained when the CBD data set was used separately was

RE = 0.615xEp1 - 18.47

R square = 0.424
Std. error = 18.69
F value = 34.85
Probability=0.0000

This model was also highly significant with regression parameters shown above. No intersection factor was significant when introduced

The model obtained using the suburban data set only was

RE = 1.377x(Ep1) - 38.16

R square = 0.608
Std. error = 20.47
F value = 105.13
Probability=0.0000

This model was also highly significant with regression parameters shown above. When the intersection factors were introduced, intersections with more than four signal phases was found to be significant. The equation obtained was

RE = 1.25x(Ep1) + 13.23P - 36.44

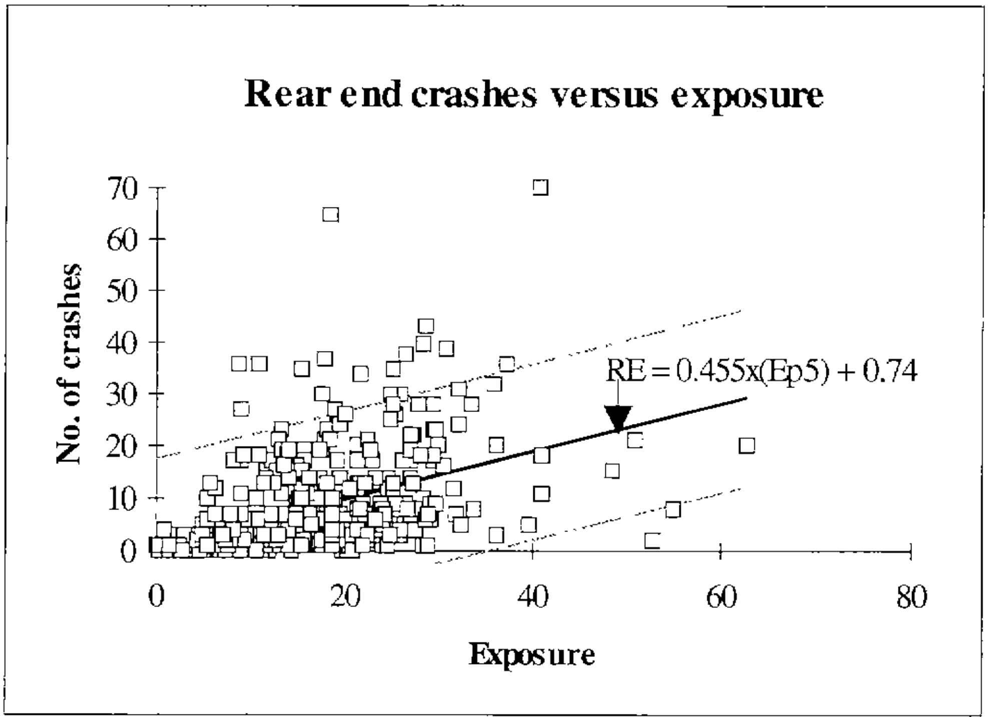
having the following parameters

R square = 0.637
Std. error = 19.71

F value = 59.78
Probability=0.0000

5.3.3 Discussion of models

Shown in Figure 7 is the plot of rear end collisions against exposure as given by equation 1 from Table XII. All the three complete models with the site factors indicated that approaches with turn left at any time with care sign experience a high proportion of rear end accidents. This situation agrees well with people's perceptions on the use of this sign. It is argued that the provision of turn left with care at any time is a safety hazard. Rear end collisions can occur more frequently as the data suggest, because a following left turn vehicle assumes that the leading vehicle has made the turn whereas infact it hasn't. The following vehicle at that time may be watching the cross traffic and not the vehicle in front and in so doing ran into the rear of the leading vehicle. Comparison of these models indicate different factors being significant in the CBD and outside the CBD. This suggest the best models to use in prediction should be the models developed separately even though there is not much difference at the five percent level between the values predicted by the complete model developed using the full data set and the separate ones. The positive correlation between the right turn ban at certain times of the day with rear end collision is more difficult to explain. Further study into the behaviour of motorists of these signs when not in use and when in use is required to understand this phenomenon. As it now stands the only appropriate reason that could be assumed may be poor knowledge of the times when these signs



Regression line ------------- 95% confidence level

Figure 7: Approach rear end accidents -exposure relationship (SA, 1988-91).

are in operation, and are then forced to react suddenly upon discovering that the turn is banned resulting in either a collision from behind or in front. The model for the whole intersection indicates that complex signal phasing in terms of number of signal phases in a cycle results in more crashes. This together with possibly lower vehicular speeds in the CBD and drivers' better knowledge of traffic situations in the CBD may results in there being fewer crashes per intersection in the CBD than elsewhere. The amount of variation explained by the model was improved when the whole intersection was considered.

5.4 SIDE SWIPE COLLISION MODELS

5.4.1 Introduction

Side swipe accidents occur between vehicles travelling in adjacent lanes or when one vehicle is trying to overtake another or is changing lanes. A crash involving any of the vehicular movements shown below is therefore classified as a side swipe accident:

Side swipe accidents are relatively uncommon at signalised intersections, only 619 (9.7% of total crashes) were contained in the whole database (see Table III). However since some approaches have very high numbers (a maximum of 61), some attention is needed. Side swipe accidents are associated with the leg of the intersection on which the vehicles were travelling similar to that of rear end collisions. Hence the same exposure measure considered for the rear end accidents was used (ie. the total sum of all traffic using the approach).

5.4.2 The regression models

a. Approach based models

Various functional form of this exposure measure were investigated. The most significant model obtained was again the linear one as shown below in Table XII. The inclusion of the site factors resulted in equation 1a. The approach with the maximum number of collisions appeared to be an outlier, having a value of more than six standard deviation above the mean. It was removed from the analysis after observing that it was having a profound influence on the final model. Models obtained using the separate CBD data are given by equations 2 and 2a and that for the suburban data are given by equations 3 and 3a. The models developed considering the flow exposure measure only were not statistically different from the one obtained when the full dataset was considered, due to there being no difference in the crash rate of this collision type between the CBD and suburban areas. However when the site factors were considered the factors found to be related were slightly different. Although the model parameters are all strongly significant, the explanatory power of these models is weak, as may be seen from the R^2 values shown in Table XIII.

Table XIII: Approach based models for side swipe crashes

Region	Formula	R^2	Std.Error	F value	Prob.
All sites	1. SW = 0.08x(Ep5) + 0.05	0.155	1.83	77.81	0.0000
All sites	1a. SW = 0.049x(Ep5)+1.31D-0.23F +2.73H +0.3L-0.15	0.241	1.74	27.61	0.0000
CBD	2. SW = 0.076x(Ep5)+0.06	0.175	1.73	38.36	0.0000
CBD	2a. SW = 0.036x(Ep5)+2.15D+2.76H +0.11W-0.65	0.308	1.58	20.61	0.0000
Suburban	3. SW = 0.086x(Ep5) + 0.1	0.140	1.91	40.47	0.0000
Suburban	3a. SW = 0.06x(Ep5)+1.08D+0.39L-0.77	0.195	1.84	20.60	0.0000

b. Model for whole intersection

The exposure measure considered was the sum of flow entering the intersection that is summing the exposure measure on each approach together. The regression equation obtained was given by:

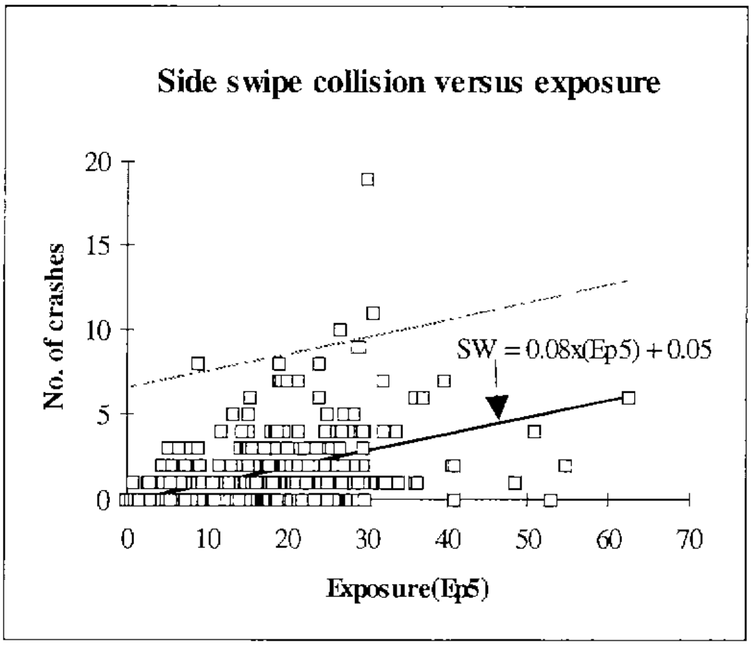
SW = 0.169xEp1 - 4.40

having regression parameters of
R square = 0.184
Std. error = 8.02
F value =62.67
Probability=0.0000

None of the intersection site factors was found significant when introduced into this model.

5.4.3 Discussion of models

Figure 8 shows the plot of side swipe crashes against exposure as given by equation 1 (Table XIII) showing the 95 percent confidence intervals. The complete models including the site factors indicate the number of lanes to be positively associated with side swipe crashes, except in the model for the CBD which indicates that this type of crash is related to the width of the road. This is to be expected since more lanes means more vehicles travelling side by side and also more possibilities for lane changes by drivers providing more opportunities for side swipe collisions to occur. The increase is, however, very modest as seen from the coefficient of the lane variable L (equations 1a and 3a in Table XIII) Approaches with multiple turning lanes increases this type of collision possibly, due to drivers encroaching into the nearest lanes whilst turning, a phenomenon which is very common with inexperienced drivers or those turning at high speeds.



———————— Regression line ------------- 95% confidence level

Figure 8: Approach side swipe accidents - exposure relationship (SA, 1988-91).

5.5 APPROACHING COLLISION MODELS

5.5.1 Introduction

This type of crashes involves all type of collisions involving vehicles travelling in the same direction on the same approach, that is all side swipe and rear end collisions. These make up about 60 percent of all crashes at signalised intersections. Signals are not installed to eliminate these types of crashes, which may actually increase at intersections when signals are installed. Separate models developed for these crash types indicated a linear relationship with the approach flow. It was thus necessary to investigate the kind of relationship that exists between these approaching vehicle collisions and the total approach flows as the exposure measure.

5.5.2 The regression models

a. Approach based models

The best regression model obtained was

AP = 0.554x(Ep5) + 0.644

R square = 0.229
std error = 9.96

F value = 126.00
probability = 0.0000

This model suggests a modest 0.6 crash with no flow, a value which was reduced when the site factors were included. The model obtained when the intersection site factors were introduced is shown below.

AP = 0.447x(Ep5)+2.03A+2.82C-2.86CBD+4.46D+2.38G+7.38I-1.64

R square = 0.438
std error = 8.50
F value = 47.96
probability = 0.0000

Site factors found to be significant included approaches with an exclusive protected right turn phase (A), right turn ban during certain times of the day (C), multiple turning lanes (D), three or more lanes at the stop line (G), turn left at any time with care sign (I), and the CBD factor. With the exception of the CBD factor all the others had positive coefficient indicating an increase in crashes where these are present. A reduction in approach crashes in the CBD is in line with the observed crash statistics showing lower crash rate per intersection in the CBD compared with other areas.

When the separate CBD data set was used the regression model was

AP = 0.483x(Ep5) - 1.22

with regression parameters
R square = 0.307
std error = 7.67
F value = 79.17
probability = 0.0000
Introduction of the site factors gave the relationship shown below.

AP = 0.275x(Ep5)+8.63C+12.48D+8.38I+5.42N+0.03

with regression parameters:
R square = 0.507
std error = 6.47
F value = 37.00
probability = 0.0000

The site factors found to be significant included approaches with right turn ban during certain times of the day (C), multiple turning lanes (D), turn left at any time with care sign (I), and approaches with more than one signal phase per cycle (N). All these factors had positive coefficient indicating an increase in crashes where these are present.

The model obtained using suburban data set was:

AP = 0.707x(Ep5) + 0.657

with regression parameters of:

R square = 0.260
std error = 10.71
F value = 86.58
probability = 0.0000

When the intersection factors were introduced the factors found to be significant included the number of lanes (L) and left turn at any time with care sign (I). The model obtained was:

AP = 0.487x(Ep5)+8.71I+3.60L-8.88

with regression parameters of:

R square = 0.443
std error = 9.29
F value = 65.67
probability = 0.0000

b. Intersection based models

The regression equation obtained based on the entire intersection was given by:

E(A) = 0.95x(Ep1) - 20.51

with regression parameters of:

R square = 0.373
std error = 28.14
F value = 68.98
probability = 0.0000

When the intersection factors were included the CBD factor and intersection with more than four signal phases per cycle (P) were found significant following the same trend as the total intersection model. The equation obtained was:

E(A) = 1.04x(Ep1) - 18.72CBD + 20.45P - 22.49

with regression parameters of:

R square = 0.542
std error = 24.05
F value = 46.03
probability = 0.0000

The model obtained when the CBD data set was used separately was

RE = 0.0.707x(Ep1) - 19.29

R square = 0.454
Std. error = 20.23
F value = 39.29
Probability=0.0000

This model was also highly significant with regression parameters shown above. No intersection factor was significant when introduced.

The model obtained using the suburban data set only was

RE = 1.693x(Ep1) - 49.25

R square = 0.626
Std. error = 24.28
F value = 112.94
Probability=0.0000

This model was also highly significant with regression parameters shown above. When the intersection factors were introduced, intersections with more than four signal phases was found to be significant. The equation obtained was

RE = 1.569x(Ep1) + 13.05P - 47.55

having the following parameters

R square = 0.643
Std. error = 23.72
F value = 59.78
Probability=0.0000

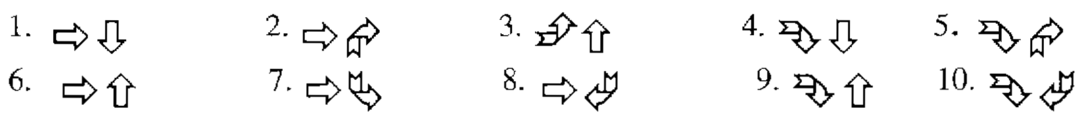
5.5.3 Discussion of models

Significantly valid models have been developed for approaching vehicle crashes using the total approach flow. However, the amount of variation explained by the models is low as seen from the R squared values. As expected approach crashes were found to be linearly related to the approach flow with some of the coefficients not different from those obtained for the rear end collisions only. This is as expected since about 80 percent of approaching collisions are of the rear end type. The dominance of rear end crashes in the approaching crash models is further reflected in the site factors found significant. The same factors found significant in the model for rear end crashes are also significant in the approaching collisions except that there are some slight differences in the coefficients of the factors. Once again the most significant factor appearing in all the approach-based models. was approaches with left turn at any time with care sign (I). For the whole intersection model. intersections with more than four phases per cycle (P) and the CBD factors were found to be highly significant. The amount of variation explained for the model based on the whole intersection was higher than the approached based models. However, the intersection based models have the disadvantage of not being able to accommodate the intersection and signal factors.

5.6 RIGHT ANGLE COLLISION MODELS

5.6.1 Introduction

In South Australia right angle crashes are defined to be collisions involving vehicles travelling on adjacent approaches of the intersection. A crash involving any of the vehicular movements shown below is therefore classified as a right angle collision:



This type of crash is the main type of collisions supposed to be eliminated by the installation of traffic signals. However, it is observed that right angle crashes constitute about 14 percent of all crashes and form the third most frequent collision type at signalised intersections. with a mean crash rate of 2.31 per intersection for 4 years (see Table II). The distribution of these crashes is not normal and is skewed positively around the mean. The maximum number of crashes recorded per approach was 12. a value quite low compared with the maximum of the other three main crash types. The operation of signals would indicate that this type of collision could occur when drivers attempt to run the right light. In data coding. right angle accidents are associated with the leg of the intersection whose stop line is closest to the point of collision. Right angle accidents between vehicles travelling on approaches 1 and 2 are associated with approach 2, between 2 and 3 are associated with 3. between 3 and 4 is associated with approach 4 and between 4 and 1 are associated with 1. This definition of right angle accidents means that for approach 1, right angle accidents are those that involve vehicles from the right. This will involve the through traffic q11 from approach 4 and traffic from approach 1, and the right turning traffic q12 from approach 4 and the right turning and through movement from approach 1. Hence the exposure measure considered for right angle collisions involved the functional form of these movements given by

$$Ep6 = (q11 \times V1) + q12 \times (q2 + q3)$$

5.6.2 The Regression models

a. Approach based models

The significant regression equations obtained are shown in Table XIII. The exposure only model obtained as shown in equation 1 of the table indicates that right angle crashes appear to be related non linearly to the exposure measure used with a low power of 0.2. This value was obtained by non linear regression method. Inclusion of the site factors resulted in equation 1a. with the only site factors entering the relationship being approaches with a right turn ban during certain times of the day(C). This factor tends to increase right angle accidents when introduced. Considering the CBD and suburban data separately gave expressions 2 and 2a, and 3 and 3a respectively. Inclusion of the site factors indicated approaches with right turn filter phase (B) and shared left turn lane to be positively related this crash type for the CBD area. For the suburban areas, right turn ban during certain times of the day (C) and approach having more than one movement phase per cycle were positively related with this crash type. Even though the models were highly significant statistically, the variation being explained is extremely low as seen from the R square values. This indicates how poorly the occurrence of this crash type depends on the traffic movements contributing to its occurrence, at least at signalised intersections. This low explanatory power may be related to the observation that signals are expected to significantly reduce right angle collisions. Where such crashes still occur at signalised intersections these may well be other site specific factors at work.

Table XIII: Approach based models for right angle crashes

Region	Formula	R^2	Std.Error	F value	Prob.
All sites	1. $RA = 1.01x(Ep6)^{0.2} - 0.30$	0.060	2.25	25.30	0.0000
All sites	1a. $RA = 0.917x(Ep6)^{0.2} + 1.84C - 0.10$	0.073	2.23	16.00	0.0000
CBD	2. $RA = 0.897x(Ep6)^{0.2} - 0.42$	0.061	2.35	11.56	0.0008
CBD	2a. $RA = 1.25x(Ep6)^{0.2} + 1.4B + 1.08J - 3.46$	0.144	2.25	10.22	0.0000
Suburban	3. $RA = 0.663x(Ep6)^{0.2} + 0.33$	0.044	2.18	11.03	0.0011
Suburban	3a. $RA = 0.64x(Ep6)^{0.2} + 0.85C - 0.6N + 0.31$	0.090	2.12	8.12	0.0000

b. Model for whole intersection

The exposure measure considered was the sum of exposure determined for all the approaches of the intersection. The regression equation obtained was given by:

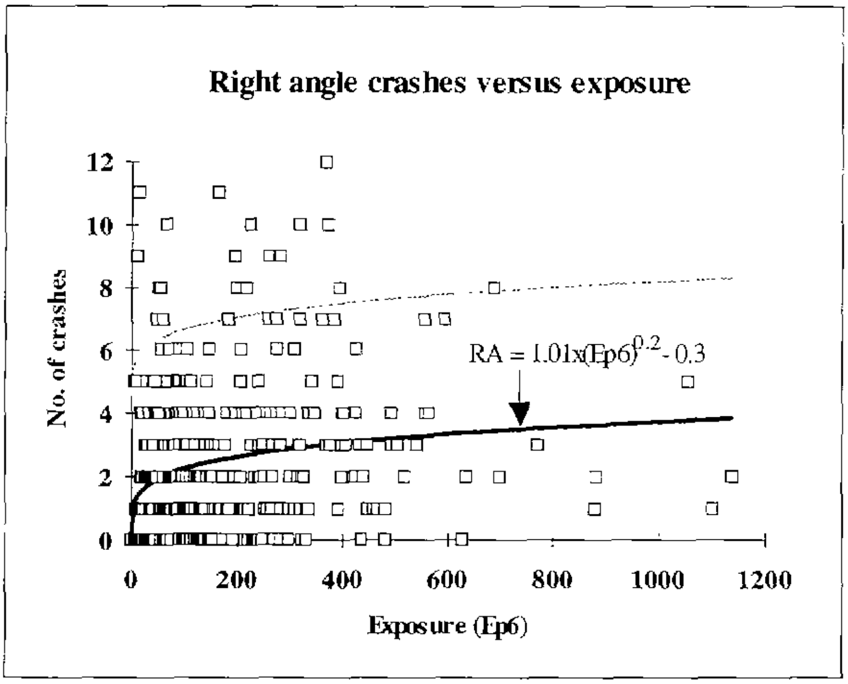
$RA = 0.757x(Ep6)^{0.2} + 0.35$

R square = 0.244
standard error = 5.21
F value = 37.94
probability = 0.0000

This model indicates 0.35 crash with no flow, a value which statistically is not different from zero. None of the intersection site factors was found significant when introduced.

5.6.3 Discussion of models

Figure 9 is a scatter plot of approach right angle crashes with the exposure measure showing the regression model given by equation 1 (Table XIII). This plot apparently shows a random distribution of crashes with exposure indicating clearly how poorly related this crash type is with the exposure measure. Drivers are most likely to run the red light during times of low traffic a situation which is independent of the total traffic through the intersection. It is very likely that if the actual volume of traffic through the intersection during the occurrence of these crashes were known and used to develop the models then more efficient models may be obtained



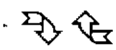
Regression line ------------ 95% confidence level

Figure 6: Approach right angle accidents - exposure relationship (SA, 1988-91)

5.7 RIGHT TURN CRASHES

5.7.1 Introduction

Right turn crashes (termed indirect right angle crashes in WA) involve crashes between vehicles travelling on opposite approaches in which at least one of the vehicles is turning right. Thus a crash involving any of the vehicular movement shown below are classified as right turn accidents:

1.  2.  3. 

It is the second most frequent occurring type of crashes at signalised intersections, making up about 17 percent of all crashes as shown in Table II. Table XIV gives a summary statistics for this crash type broken down into categories depending on the type of right turn signal control employed. The crash distribution is highly skewed positively around the mean with a mean crash occurrence of 3.39 per approach for the four year period and a maximum of 35 crashes. In terms of the various right turn signal controls employed, the exclusive protected right turn phase is found to be the least hazardous and the most dangerous being approaches with both the protected/filter phases in operation, as seen from the mean crash value per approach shown in Table XIV. Right turn crashes are associated with the leg of the intersection from which the turning vehicle has come. Detailed studies of all the right turn accidents showed that only four accidents involved vehicles of movement type 3 shown above. Hence this type of crash is rare and not considered a problem. As a result two types of exposure measures were considered, one taking these movements into consideration and the other ignoring them. The exposure measures thus considered were for approach 1 defined as

Ep7 = q3 x (q7 + q8) neglecting movement type 3 and
Ep7a = q3 x (q7 + q8 + q9) including movement type 3

Table XIV: Summary statistics for Right turn crashes

Parameters	All data	Protected	Filter	Filter/protected
No. of Approaches	339	82	220	35
Mean	3.39	2.30	3.71	4.06
Median	2	1	2	3
Standard Deviation	4.45	4.44	4.43	4.34
Kurtosis	16.78	29.69	16.21	3.97
Skewness	3.33	4.90	3.16	1.90
Lower quartile	1	0	1	1
Upper quartile	5	3	5	5
Minimum	0	0	0	0
Maximum	35	33	35	19

5.7.2 Regression models

Both linear and power forms of these exposure measures were investigated. Models obtained by the use of exposure form "Ep7a" did not provide any improvement and so were not pursued any further. Four different cases of this type of accident were investigated. The first was all right turn accidents and the remaining three depending on the type of right turn controlled employed (ie whether protected, filter or both protected/filter right turn controlled). The regression equations for the four cases are shown below and identified by:

1. RT = all right turn accidents

2. RT1 = protected right turn phasing
3. RT2 = filter right turn phase
4. RT3 = both protected and filter right turn phasing operate

a: All right turn crashes

The total right turn crashes were difficult to model. The model obtained using the exposure measure defined above was highly insignificant as seen from equation 1 in Table XV. They were found to be loosely related to the right turning flow q, and the sum of the opposing conflicting flows Q in the form of

$$RT \alpha \quad q^a Q^b$$

where the constants a and b were found to be different from each other. This result is similar to that obtained by Hall (1986). The result obtained is given by equation 1a in Table XV

b: Right turn crashes under protected right turn phase

All the functional forms of the exposure measure used including those developed by Council at el (1987) were found to be insignificant for the protected right turn phase. The Council et al (1987) exposure measure was related only to the two right turning flows (left turning flows in the USA) if the two movements were allowed to move at the same time and independent of the flow if otherwise. This seemed to suggest that right turn crashes are independent of the traffic contributing to this type of collision. Considering the site factors it was found that right turn collision in a protected right turn phase were related positively with shared right turn lane (E), approaches with more than one signal phase per cycle (N) for some movement and if the intersection is coordinated or not (K). These factors contributed a total of about nine crashes over the period considered.

b: Right turn crashes under permissive (filter) and both permissive/protected right turn phase

Both filter right turn phasing and filter/protected right turn phases were found to be linearly related to the exposure measure as shown in Table XV equations 3 and 4 respectively. Inclusion of the site factors resulted in equations 3a and 4a for the filter only phase and both filter/protected right turn phases respectively.

Subsection b and c of Tables XV are the results obtained using the separate data from the CBD and suburban areas. These gave a slightly different equations especially when the site factors were included, even though some factors were found to be common to all three different models.

Due to the low explanatory powers obtained from the exposure measures used, an attempt was made to investigate whether the exposure measures developed by Council at el (1987) would provide an improvements on the models obtained. However, none of these exposure measures provided any better models. Most of the models obtained were not even significant. This seem to suggest that those exposure measures are not applicable to the SA conditions assuming those

Table XV: Approach based models for right turn crashes

a. All data set

Formula	R^2	Std.Error	F value	Prob.
1. $RT = 0.002x(Ep7) + 3.32$	0.001	4.46	0.387	0.5342
1a. $RT = 2.02q^{0.06}Q^{0.3} - 0.97$	0.070	4.30	26.40	0.0000
1b. $RT = 2.86q^{0.06}Q^{0.3} + 2.16B + 1.53E - 1.13J - 4.36$	0.149	4.11	15.71	0.0000
2. $RT1 = 2.41 - 0.0012x(Ep7)$	0.001	3.30	0.009	07629
2a. $RT1 = 5.58E + 1.8K + 3.25N - 1.81$	0.219	3.93	8.56	0.0001
3. $RT2 = 0.14(Ep7) + 1.43$	0.333	3.62	110.65	0.0000
3a. $RT2=0.165(Ep7)+2.91C+1.21E-1.35CBD+1.75I+1.69N+0.81$	0.406	3.43	30.28	0.0000
4. $RT3 = 0.123(Ep7) + 0.74$	0.209	3.85	9.99	0.0034
4a. $RT3 = 0.095(Ep7)+5.14M+0.57W-5.77$	0.494	3.09	12.06	0.0000

b. CBD data

Formula	R^2	Std.Error	F value	Prob.
1. $RT = 2.95q^{0.06}Q^{0.3} - 3.01$	0.083	4.50	14.47	0.0002
1a. $RT = 4.59q^{0.06}Q^{0.3} + 3.08B+2.03E- 10.46$	0.128	4.87	8.24	0.0000
2. $RT1 = 5.96 - 0.01x(Ep7)$	0.018	7.63	1.29	0.2738
2a. $RT1 = 1.83E +1.42$	0.231	1.35	5.5	0.0343
3. $RT2 = 0.15(Ep7) + 0.57$	0.413	3.73	92.37	0.0000
3a. $RT2 = 0.18(Ep7)+2.6E-1.31$	0.406	3.43	30.28	0.0000

c. Suburban data

Formula	R^2	Std.Error	F value	Prob.
1. $RT = 1.48q^{0.06}Q^{0.3} + 0.1$	0.058	3.64	12.52	0.0005
1a. $RT = 2.34q^{0.06}Q^{0.3}+2.49B+1.66E - 1.75J - 2.69$	0.223	3.30	14.41	0.0000
2. $RT1 = 1.49 + 0.009x(Ep7)$	0.010	3.07	1.64	0.2056
2a. $RT1 = 3.4E + 1.79N +0.07$	0.13	2.88	5.59	0.0059
3. $RT2 = 0.14(Ep7) + 2.29$	0.224	3.28	26.34	0.0000
4. $RT3 = 0.124(Ep7) + 0.67$	0.210	3.91	9.78	0.0037
4a. $RT3 = 0.095(Ep7)+5.16M+0.57W-5.76$	0.494	3.13	11.72	0.0000

measures to be accurate. This may be due to many factors including the operation of the signals and regional differences in driver behaviour. When the site factors were introduced, equation 1a in Table XV was obtained indicating approaches operating the right turn filter phase (B) and shared right turn lane (E) to be significant.

b. Model for whole intersection

The exposure measure considered was the sum of exposure determined for all the approaches of the intersection. The regression models obtained for crashes in the protected right turn phase and both protected/filter phases were found to be insignificant. The model obtained for the filter phase right turn crashes was

RT2 = 0.105xEp + 5.94

R square = 0.251
standard error = 7.69
F value = 25.41
Probability = 0.0000

None of the intersection site factors was found significant when introduced

5.7.3 Discussion of models

All right turn crashes grouped together irrespective of the right turn phase employed was found to related with the right turning flow, q, and the sum of the conflicting flows Q assuming different exponents. The explained variation is however very low as compared with those obtained when the data were disaggregated based on the type of right turn signal phasing employed as given by the various R square. This result is in agreement with those obtained by Hall (1986) and Huaer (1986). When the site factors were introduced approaches with filter phase (B) and shared right turn lane (E) were found to contribute to an increase in right turn crashes. The contribution of the filter phase is understandable and expected. That due to the shared right turn is not quite clear and requires further study on the field to visualise the operation of these movements. It is possible that the turning vehicle sight distance and view may be blocked by the opposing turning vehicle or the through movement if it is following one.

For an exclusive protected signal phase, right turn collisions were found to be unrelated to exposure. This collision type can only occur here if drivers run the red light. The no relationship phenomena obtained here does agree with the second part of the exposure measure given by Council et al (1987) stated earlier. The disagreement in the first part may be due to differences in signal operations in SA and the USA. In SA, most right turning vehicles move with the through movements whereas this may not be so in the USA.

Valid linear relationships were found between right turn crashes and exposure for the filter and both filter/protected right turn phases. These collision types occur possibly by turning drivers inability to select appropriate gaps in the opposing traffic stream (Howie and Ambrose, 1989). Shown in Figures 10 and 11 are the plots of right turn crashes with exposure. No factor was found significant for the filter right turn phase when the suburban data was used separately indicating that the factors found significant when the full data set was used came as a result of combining both the CBD and suburban data. Shared right turn lane (E) was found to be significant in the models using the full data set and for the CBD area. Models for both filter/protected right turn phase indicated three leg intersections (M) to be associated with high right turn crashes. This is in agreement with the findings of Hughes (1990). The approach width was also found to be positively correlated with right turn crashes. In most of the intersections used the approach width is half the total width of the road. Thus wide approach width implies a large turning radius for the right turning vehicles. This means longer time spent in the intersection and an increase in the probability of a through vehicle colliding with the turning vehicle.

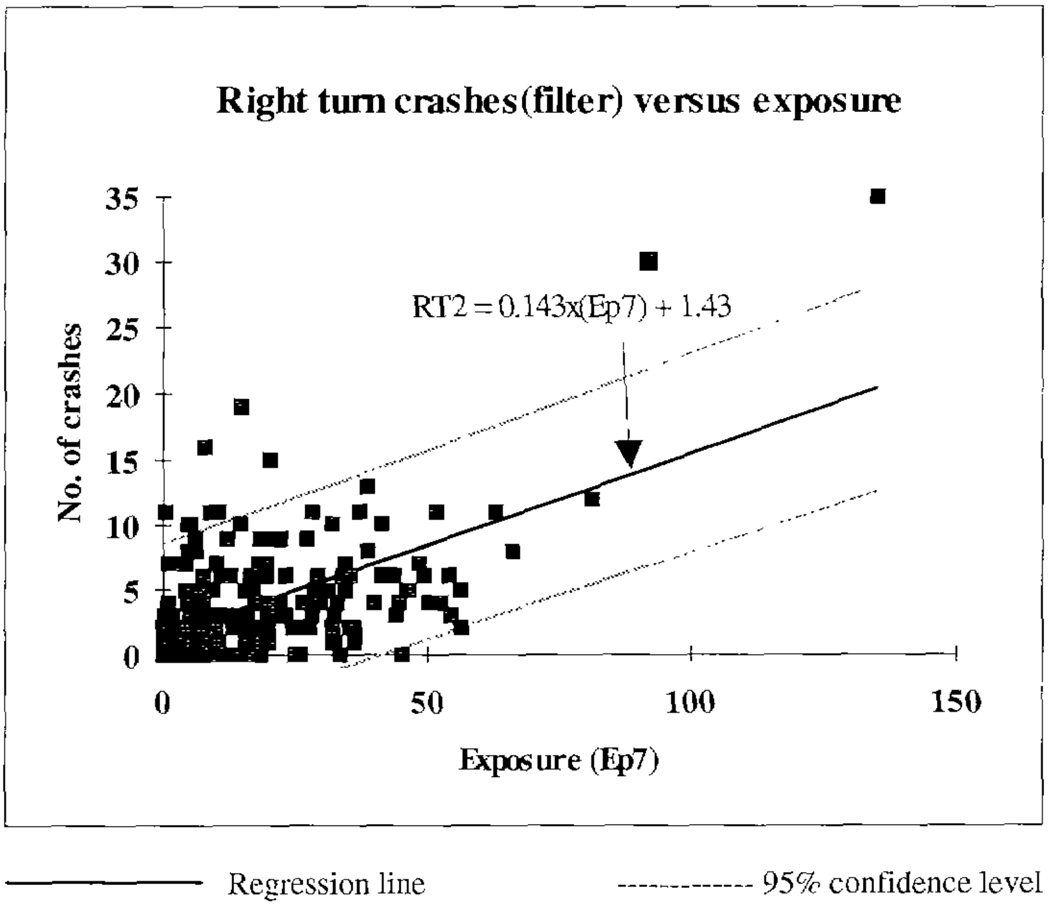
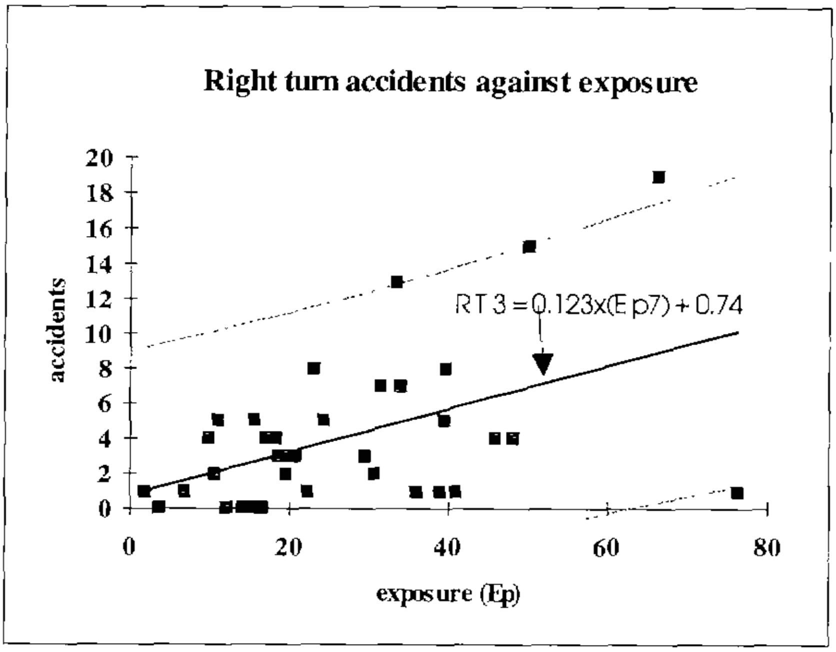


Figure 10: Approach right turn crashes (Filter phase) exposure relationship (SA, 1988-91)

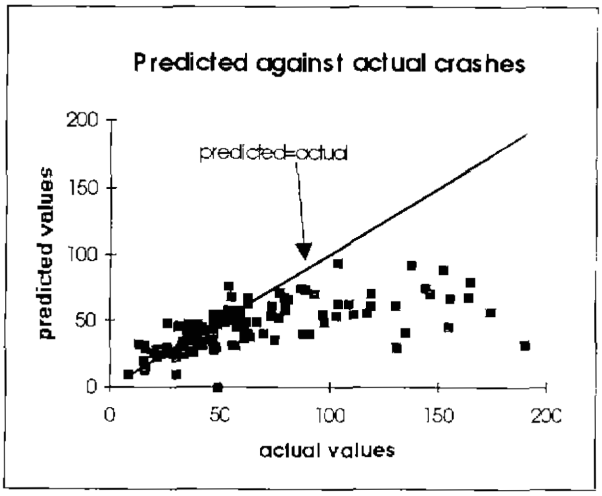


——————— Regression line ------------- 95% confidence level

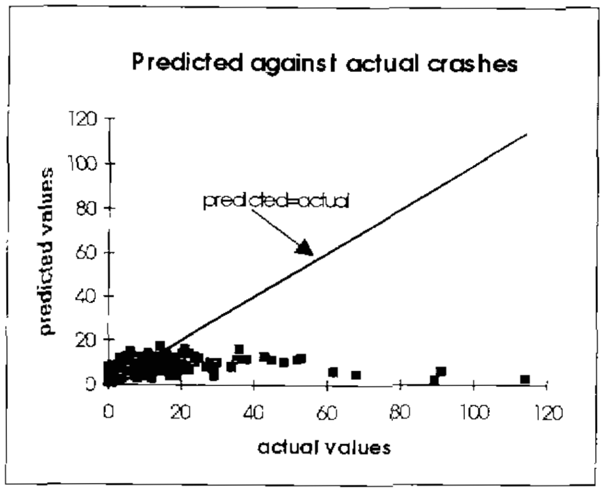
Figure 11: Approach right turn accidents (both filter/protected phases) exposure relationship

5.8 VALIDATION OF MODELS USING WA DATA

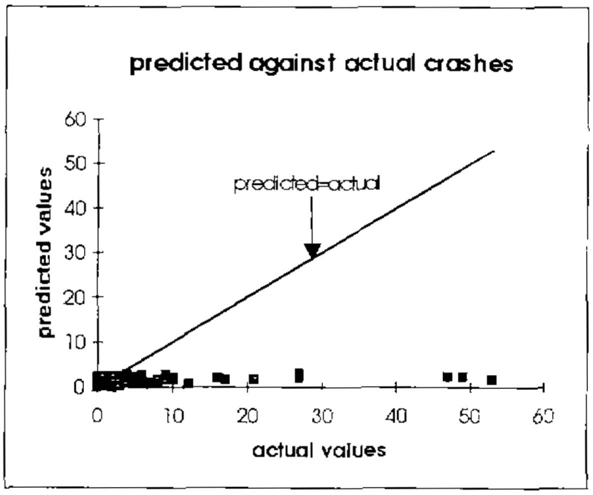
On the whole, validation of the models using WA data indicated a poor fit to the data meaning these models could not be used to predict crashes in WA and possibly other areas with different traffic flow and crash characteristics from that of SA. This is not surprising given that the SA data did not fit the WA models. Shown in Figure 12 are plots of predicted values against actual values for the various crash types. It can be observed that the model for the total intersection crashes predicted the actual values quite well for crash frequency of up to about 60 as seen for Figure 12a. Above this values the model was always underestimating. For the various crash types the models underestimated the crash frequency most of the time (see Figure 12b-12f). The study has thus shown that regression models developed from one area cannot be used to predict crashes from different areas without some form of re-calibration. During the model fitting process it was however found that there were some agreement in the predicted and actual values if the crash rates in the two areas were comparable.



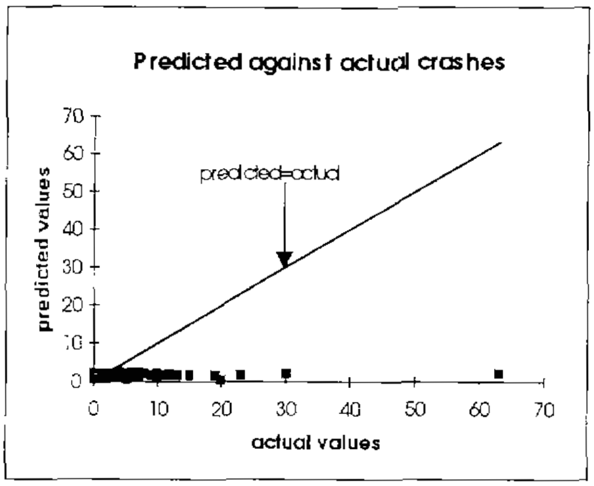
a: Total intersection crashes



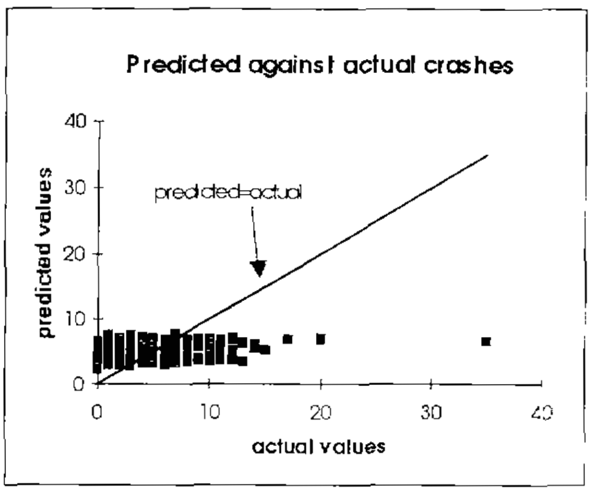
b: Rear end crashes



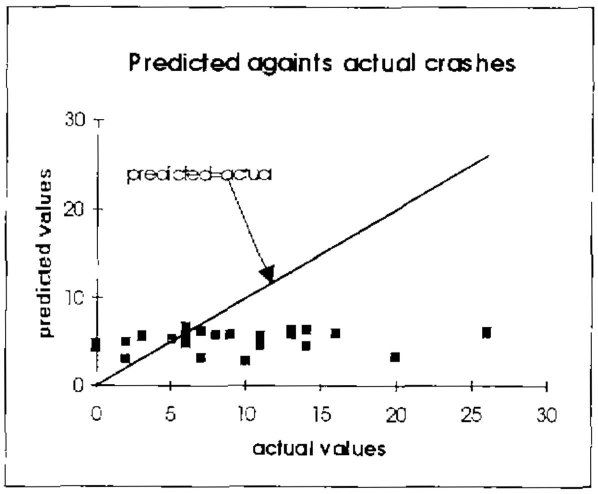
c. side swipe crashes



d: right angle collisions



e. Filter phase right turn crashes



f. Both filter/protected phases

Figure 12: Plot of predicted crashes against actual crashes recorded (WA, 1986-89)

6.0 IMPLICATIONS AND USES OF THE MODELS

The objectives of this study was to develop predictive models for crashes at intersections and to formulate planning techniques that would enable traffic engineers to be proactive in designing traffic management schemes that reduce the likelihood of crashes. This can be achieved in the use of the models in predicting future crashes, estimation of the intersection safety and the impact of a particular management scheme. The estimation of intersection safety will provide means of comparing the safety of different intersections.

6.1 PREDICTION OF CRASH OCCURRENCE

The main use of predictive models is predicting future outcomes. The relationships obtained could be used to estimate the expected number of each collision type given a the traffic flow and the intersection site factors. This will enable traffic engineers and planners to be in a position to evaluate the effects of signals at a particular intersection before installation or due to changes in signal design, or changes in traffic flow as a result of factors such as closure of a nearby street, construction of a freeway nearby or changes in the surrounding landuse. The investigation of whether the installation or modification of signals increase rear end crashes and reduce right angle collisions can be undertaken by the use of these relationships. Currently, such analyses has to be performed by before and after studies with a comparison with a suitable control sites. However, selection of appropriate control sites is often difficult. The models developed could easily be integrated into computer planning packages to assess the safety impact of different planning alternatives before implementation.

6.2 DESIGN FEATURES RELATED TO SAFETY PERFORMANCE

Some signal and intersection design features have be found to be correlated with the frequency of crash occurrence at a site and hence affect safety performance. The most influential factors modifying crash frequencies by more than five over a four year period include the following:

<u>Number of lanes (L and G) at the stop line</u>
The number of lanes at the stop line was found to be positively related with approaching collisions (rear end collisions and side swipe collisions). This shows that approaches with more lanes at the stop line will experience high frequencies of this collision type. For example, approaches with more than three lanes at the stop line will record about two more collisions over the period of the approaching collisions type compared to those with less than three lanes.

<u>Approach width (W)</u>
The approach width was also found to be positively correlated with right turn crashes and side swipe collision (CBD area only). Wide approach width implies a large turning radius for the right turning vehicles. This means longer time spent in the intersection and an increase in the probability of a through vehicle colliding with the turning vehicle. Wide approach width also increase the likelihood of more vehicles travelling side by side and the probability of more overtakens by vehicles taking place. Hence increase in the probability of side swipe collisions occurring.

Multiple turning lanes (D)
Multiple turning lanes was found to be correlated with rear end and approaching collisions and so should be used only when appropriate.

Turn left at any time with care sign (I)
This is the single most influential factor found to increase the occurrence of approaching crashes especially rear end collisions. It increases the frequency of these collisions by over seven crashes over the time period. It should therefore be employed with caution and only after determining its over net benefits.

Number of intersecting legs (M).
Approaches with both permissive and protected right turn control at three leg intersections experience about five more right turn crashes than their counterparts in the four leg intersection. This means this control type is not suitable for the three leg intersections. As will be shown later on, both permissive/protected signal phasing is not appropriate for reducing right turn collisions, and should therefore not be used if a right turn control is to be provided to reduce the occurrence of right turn crashes.

Right turn ban at certain time of the day (C)
This control type was found to result in an increase in the three most frequently occurring collision types at signalised intersections (rear end, right angle and right turn crashes). The reason for the occurrence of these collisions may be poor knowledge of the times these signs are in operation and/or poor visibility, resulting in drivers being forced to react suddenly upon discovering that the turn is banned. It is therefore necessary that these signs be well illuminated and place at a sufficient distance from the intersection to allow drivers enough time to take the appropriate action. Further study is required to relate the time of crash occurrences to the time of the ban. This will help determine whether these crashes occur when the ban is in operation or not.

Right turn control
The frequency of right turn collisions is found to be influenced by the type of right turn control employed. Right turn crashes under the protected right turn phase were relatively small in numbers, and were found to be unrelated to the exposure measure. On the other hand under the permissive and both permissive and protected phases right turn crashes were found to be related linearly with exposure. The coefficients of these linear models were statistically not different from each other, indicating similar risk to collision under both control types. This implies that, for positive control of right turn crashes, the right turn phase should be fully controlled. Any attempt to permit a permissive phase at any stage of the cycle will not help reduce the occurrence of this collision type.

Number of signal phases
Intersections with complex signal phases having more than four phases per cycle were found to have increased intersection collisions, particularly rear end crashes (see section 5.4.2b). This implies that the optimum number of signal phases per cycle for the types of intersection considered in this study should be limited to four whenever possible. Approaches having more

than one green phase per cycle (N) were found to have increased approach number of rear end and right angle collisions in the suburban areas. (The signal design philosophy employed in the Adelaide CBD means that approaches with more than one green phase are rare, if any at all).

Other factors influenced the occurrence of collisions, but only marginally. These include shared right turn lane (E) and the permissive right turn control (B), which are positively correlated with right turn collisions, shared left turn lane (J), protected right turn control (A). Shared left turn lane is negatively correlated with right turn crashes while protected right turn control is positively related to approaching collisions. Some of the links between these factors and crash occurrences are expected, others are more difficult to explain and therefore call for further study, as discussed in greater detail under section 7.2.

6.3 INTERSECTION SAFETY

For the purposes of this report, intersection safety is defined as the number of crashes per unit time that is expected to occur in the long run at the intersection. This is another area where predictive modelling is of prime importance. It could be used in estimating the level of safety of an intersection and thereby enabling the comparison of the safety of one intersection with another. It could also be used in estimating the likely safety impact of signals before installation. The models could be used to estimate the number of crashes expected E(A) at each candidate intersection. The difference (d_i) between the actual (x) and expected crash frequency can then be determined as:

$$d_i = x - E(A)$$

This difference could then be used to determine which intersection is safer, or even used to rank sites for selection for treatment.

The use of the above models will predict that intersection with similar characteristics in terms of flows and site factors to have the same number of crashes. However, it is well known that crash occurrence varies from site to site and even at the same site from one period to another. It is therefore appropriate to account for this variations in crash occurrences. In this regard the approach suggested by Persaud (1988) could be used to refined the predicted values. He suggested that, based the assumption that road crashes follow the Poisson law, the expected number of crashes at any site could be estimated from the actual crash observed (x) and that estimated from the regression model E(A) by the relation

$$E(A/x) = x + [E(A)/Var(x)][E(A) - x]$$

where

E(A/x) is the expected number of collisions given that x collisions has occurred in a certain period of time and
Var(x) is the variance of the observed crash at the site.

The refined estimate could then be used in estimating the safety of intersections and assessing the impacts of signalisation as described above.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 SUMMARY OF FINDINGS

This report describes a study of road crashes at intersections in South Australia. A database of intersection crashes by type and severity, intersection traffic flows, geometry, control, and design features was assembled. This database was used in an analysis of the crash situations at selected signalised intersections and roundabouts and the development of predictive models for crashes at signalised intersections. A total of 6391 crashes at 115 signalised intersections and 436 at 10 roundabouts over the four year period from 1988 to 1991 were studied. The main findings include the following.

7.1.1 Crash statistics

1. The mean accident frequency over the period was 55.57 crashes per junction (ie. 13.99 crashes per junction per year) for signalised intersections and 43.6 (ie. 10.90 per junction per year) for roundabouts.

2. The crash rates per million vehicles entering the intersections were 0.93 and 1.29 for signalised intersections and roundabouts respectively. Based on the small sample of roundabouts investigated it was found that at higher flows roundabouts experience a higher crash rate than signalised intersections with similar flows.

3. Intersections in the Adelaide CBD experienced a proportionally low number of road crashes but a higher traffic flow density than elsewhere in the Adelaide metropolitan area. The low crash rate and frequency may be due to low speeds and the extra care taken by drivers due to the higher levels of commercial activities and pedestrian-vehicle interaction in the CBD. It is possible that the simpler signal phasing arrangements employed at the CBD intersections had some bearing on this result, although further research is needed before a more definitive finding is possible.

4. Signalised intersections in SA experienced higher traffic flows, lower crash frequencies and rates when compared to similar intersections in WA.

5. Analysis of the accident by type showed that the most frequently occurring crashes are rear end crashes (52.3% and 36.5%), right turn crashes (18.2% and 3.4%), right angle crashes (14.1% and 22.0%) and side swipe crashes (9.7% and 30.4%). The values in brackets are the proportions for signalised intersections and roundabouts respectively. These account for over 90 percent of all crashes at signalised intersections and roundabouts.

6. Roundabouts experiences more side swipe crashes and fewer right turn crashes than signalised intersections with comparable traffic flow.

7. Right angle crashes are supposed to be eliminated by the installation of traffic signals. The number of reported road crashes of this type suggested otherwise, implying that signals are

unable to eliminate this crash type altogether despite the known studies indicating a reduction in the number and severity of right angle crashes after the installation of signals. On the whole, it forms the third most frequently occurring road crash type and so should be of great concern. More detailed research may be required to investigate the circumstances leading to right angle collisions at signalised intersections. For instance, do such crashes result from illegal 'red light running' by some drivers? Do they tend to occur at times of low traffic demand? However, the number of collisions per approach was small compared to the other main crash types (a maximum per approach of 12 in the database).

8. Approaches with both protected and permissive right turn phases were found to have the highest crash rate among the three right turn signal controls in use followed by the permissive (filter) movements and lastly the fully protected phase. The protected right turn phases were found to be the most effective in reducing right turn collisions.

7.1.2 Regression results

1. Valid predictive models can be developed for crashes at intersections based on the flows of only the movements contributing to that type of crash by means of regression techniques. The relationship obtained from regression models are associative in nature, however, the large number of explanatory variables considered provide a strong indication of cause and effect. The amounts of variation explained by the various models is mixed, but generally low to medium. Most of the regression equations have negative constant terms which means that the use of only the exposure term will overestimate the number of crashes, and also that crashes of the particular type studied will occur after a certain level of flow has been reached.

2. For the SA database, the square root of the product of the cross flow was found to be a better predictor of crashes at signalised intersections than the total sum of flows through the intersection. This result was different to that found by Hughes (1990) for WA. The reason for this difference is unclear and would need further investigation, but one contributing factor could be the extensive use of one-way streets in the Perth CBD, which contributed many of the intersections in the WA database. In a network of one-way streets, for certain intersections the cross product of the conflicting flows is zero. In such situations the total sum of flows would be a more useful predictor of the total intersection crashes.

3. Significant models have been developed for each main crash type based on individual approaches to the intersections and for the whole intersection. The approach-based crash-flow models enable a particular crash type to be related to functions of the flow movements contributing to that type of collision. This approach is the preferred option whenever possible as opposed to a model for total intersection crashes. Apart from using only the flow movements involved in the particular collision type, the approach-based models make it possible to consider the various intersection geometry and signal factors which at the same intersection may be different for each approach, and which are therefore impossible to use in models based on the whole intersection.

4. Rear end, side swipe and approaching collisions were found to be linearly related to the total approach flow, which is reasonable given the nature of these crashes. The number of lanes was found to be significant in the models for these types of crashes. This can be expected especially in the case of side swipe crashes judging from the definition adopted for it, as the more lanes there are the more vehicles will be travelling side by side or tending to change lanes. The other factors found to be significant include turn left with care at any time sign which alone contribute about seven crashes. This confirms the perception of safety people tend to have of this manoeuvre.

5. Right angle collisions were found to be weakly related to exposure as observed by the plot of the right angle crashes and the exposure measure and the exponent of the exposure (0.2) obtained from the regression model (see Table XIV and Figure 9). These models do not produce efficient estimates due to the wide variability associated with them. With the exception of the collisions of this type resulting from vehicle failure (which were rare from the data used), this type of collision would be eliminated if all drivers obeyed the traffic signals.

6. Approached based total right turn collision was found to be related to the product of the right turning movement (q) and the opposing conflicting flows (Q), but with each of these movements raised to a different power.

7. No significant relationship was found between crashes and the flow exposure for right turn crashes under the protected right turn signal phase. Vehicle collisions under the protected right turn phases presumably come about by some drivers running the red light. It is likely that these collisions will be correlated with the actual number of vehicles running the red light. As such, the result obtained may be extended to imply that the number of drivers running the red light is independent of the amount of right turning vehicles and the corresponding conflicting flows. More detailed research may be required to investigate the circumstances leading to right turn collisions at signalised intersections operating the protected right turn phase. For instance, do such crashes result from illegal 'red light running' by some drivers? When do they occur for instance at times of low traffic demand?

8. Right turn collisions under the permissive and both permissive/protected right turn signal phases were found to be linearly related to the product of the right turning flow and the opposing conflicting flows.

7.1.3 Site and signal factors

1. Intersection factors found to be correlated with intersection crashes include turn left at any time with care sign (I), double turning lanes (D), number of lanes (L), more than three lanes at the stop line (G), one way streets (H), shared left (J) or right turn lane (E) and width of approach lane (W).

2. The provision of turn left at any time with care sign (I) is associated with an increase in the number of road crashes especially approaching crashes (rear end and side swipe crashes). However its use should not be discourage outright at this stage. [This sign is usually employed at left turn slip lanes to increase the intersection capacity]. Rather, detailed investigation into its use

and the circumstances resulting into these collisions is required. This should consider its advantages which include increase capacity, time and energy saving and for that matter less adverse environmental impacts.

3. The intersection signal factors found to be significant in the regression models include approaches with the protected right turn phase (A), the filter or permissive phase (B), banned right turn at certain times of the day (C), and more than one signal phase per cycle (N) for a given approach. For the total intersection crashes, the CBD factor was found to result in decrease in crashes whilst intersections operating on more than four signal phases (P) contribute to an increase in collisions.

7.1.4 Closure

1. The specific models developed for SA may not have wide general predictive capability. They may be useful only in predicting crashes in areas with similar signals operations, landuse and comparable crash rates. These can be inferred from the different relationships obtained from the use of the separate CBD and suburban data sets and the inability to accurately predict the WA crashes. Comparison of the models with those obtained from WA (Hughes, 1990) indicates that crashes of a particular type may be related to different functional form of the contributing flow movements in the two data sets. This implies that specific regional analyses are required to establish valid local models for planning and design purposes. The analysis however, has provided valuable guidance for the development of models for other sites.

2. Finally, the study has shown that different crash types are related to different forms and functions of the various traffic movements contributing to the type of crash. The best approach therefore to be adopted in developing predictive models for crashes at intersection is to desegregate the crashes by type and relate each crash type to a function of the flow of the movements contributing to that crash type. Separate models need to be developed for the CBD and suburban areas if the traffic flow characteristics and signal operations are different.

7.2 RECOMMENDATIONS

7.2.1 Rules of thumb

Valid predictive models have been developed for the total and the main types of crashes at signalised intersections. These models do not have wide general applicability and are therefore recommended for use under SA conditions or possibly in areas with similar traffic and signal operating conditions. It has been shown that different crash types relate to different functions of the traffic movements related to that type of collisions. The best predictor of crashes is thus the various traffic movements contributing to that type of collision. On the basis of the outcomes of the SA analysis the following broad conclusions arise

- models may not be directly transferable from one city to another

- reporting rate and definition of crashes can have a significant impact on the analysis and transferability of the results

- different models may be appropriate for the CBD and suburban conditions

- where possible desegregate crashes into the different crash categories

- approaching crashes are the single biggest type and more effort should be put into modelling them.

- right angle and protected right turn collisions are uncorrelated with flow and are not amenable to models of this type.

- the inclusion of a small number of site factors can significantly improved models

These broad conclusions are discussed in greater detail and related to SA results in the next section.

7.2.2 Models to use

As stated earlier, different crash type relate to different function of the traffic movements contributing to their occurrence. Different models are therefore required for each crash type. This implies that crashes should be disaggregated into the various crash categories and separate models developed for each. Approached based models enable the analyst to

1: disaggregate the crashes by type and relating it to the traffic movements contributing to that type of crash and

2: introducing the various intersection geometry and signal factors into the models.

Approached based models are the option to take when developing predictive models for crashes at intersections. They should be used whenever possible to predict crash frequencies. The individual crash type estimates can then be summed to obtain an estimate of the total crashes at the site The following specific recommendations are therefore made on the type of exposure to use in developing models for the various crash types and the models to use in estimating crash occurrences at signalised intersections under SA conditions:

Table XVI: Recommendations

TITLE	RECOMMENDATION NUMBER	RECOMMENDATION
Rear end collisions pp.28	1	For model development rear end crashes should be related to the sum of approach flows. Recommended models for SA CBD areas RE = 0.408x(Ep5) - 1.28 RE = 0.208x(Ep5)+8.13C+10.1D+8.78I+5.62N-0.2 Recommended models for SA suburban areas: RE = 0.408x (Ep5) + 1.01 RE = 0.396x(Ep5)+7.75I+2.98L-7.07
Side swipe collisions pp.31	2	For model development side swipe crashes should be related to the sum of approach flows. Recommended models for SA SW = 0.08x (Ep5) + 0.05 for all sites; SW = 0.036x(Ep5)+2.15D+2.76H+0.11W-0.65 for the CBD area and SW = 0.06x(Ep5)+1.08D+0.39L-0.77 for suburban area
Approaching collisions pp33	3	In situations where side swipe crashes are low in numbers such as at signalised intersections a single model could be developed to cater all the approaching collisions (ie rear end and side swipe crashes). The exposure measure to use should be the sum of approach flows. Recommended models for SA CBD areas AP = 0.483x(Ep5) - 1.22 AP = 0.275x(Ep5)+8.63C+12.48D+8.38I+5.42N+0.03 Recommended models for SA suburban areas: AP = 0.707x(Ep5) + 0.657 AP = 0.487x(Ep5)+8.71I+3.60L-8.88
Right angle collisions pp.37	4	Right angle crashes are weakly related to the sum of the product of the various conflicting flow movements. The crash frequency was random over the exposure range making model development difficult. Model development using the procedure adopted in this study is therefore not recommended. Rather, an approach based on studying the consequences leading to the occurrence of this crash type will be more appropriate.

Table XVI: Recommendations (continuation)

TITLE	RECOMMENDATION NUMBER	RECOMMENDATION
Right turn crashes for the protected phase pp.41	5	Right turn crashes under the protected signal phase is uncorrelated with the flow exposure
Right turn crashes for the filter phase pp.41	6	Models for right turn crashes under the permissive or filter signal phase should be related to the product of the right turning movement and the opposing conflicting movements. Recommended models for SA conditions RT2 = 0.14x(Ep7) + 1.43 RT2 = 0.18x(Ep7) + 2.6E - 1.31 (for CBD area only)
Right turn crashes under both filter and protected phase pp.41	7	Model for right turn crashes under both permissive and protected signal phase should be related to the product of the right turning movement and the opposing conflicting movements. Recommended models for SA conditions RT3 = 0.123x(Ep7) + 0.74 RT3 = 0.095x(Ep7)+5.14M+0.57W-5.77

6.2.2 Further research

The study has shown that valid predictive models can be developed for crashes at signalised intersections. Some of the findings were expected, but others were difficult to explain and understand and therefore require further study. The following areas are therefore recommended for further study.

1. Approaching collisions are the dominant type of crashes at both signalised intersections and roundabouts. A study is therefore required to look more closely at these crashes to acquire more knowledge into their occurrence. The improved knowledge will then enable the appropriate design methods to be adopted which will help reduce the occurrence of these crashes.

2. The occurrences of right angle collisions and right turn collisions under the fully protected right turn phases were observed at some sites and found to be loosely and uncorrelated with the flow movements contributing to their occurrences. The manner and reason for their occurrences is still not clear. Further study to investigate the consequences leading to their occurrences and when and how they occur is required.

3. Turn left at any time with care sign (I) and right turn ban during certain times of the day (C) shared right turn lane (E), number of lanes (L) were found to be the prominent factors to be correlated with rear end collisions and appeared in most of the models for the other collision types. Further study is therefore required to investigate the causal links between these factors and crash frequency. This study should also investigate the operations of these factors and access their overall impact on the transport system including safety, economic and environmental. This would enable a decision to be made on the use of these factors as appropriate traffic control measures.

4. As stated in section 6.2.2 techniques have been developed to use the history of the crash occurrence at a site to account for the variations in crash occurrences known to exist at intersections. A follow-up study is required to examine the potential for adjusting the general predictive models taking into account the crash history of the site.

5. Lack of comprehensive flow data prevented development of models for other types of intersections particularly roundabouts. A further study is thus needed to develop models for these intersections with the availability of turning flow data.

6. A limitation with the adopted modelling process involve the residual error being normally distributed. The least square regression method requires this characteristics to obtain optimum solution. The normally distributed error structure may not be suitable for road crashes. The use of specialised regression procedure like the general linear regression method, with the option of being able to specify the distribution of the error structure may be more appropriate.

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APPENDIX

Table XVII: Proportion of total AM and PM peak hour flows of Daily Traffic for CBD intersections

INTERSECTION DETAILS			INTERSECTION APPROACH			
STREET1	**STREET2**	**JUNCT_ID**	**North**	**East**	**South**	**West**
Hindley St	King William St	102	0.1645	0.0000	0.1561	0.1366
King William St	Currie St	103	0.1648	0.1739	0.1614	0.1739
King William St	Waymouth St	104	0.1631	0.1727	0.1644	0.1727
King William St	*Wright St*	*108*	*0.1883*	*0.1869*	*0.1896*	*0.1869*
Sturt St	King William St	109	0.1677	0.2041	0.1737	0.1875
Gilbert St	King William St	110	0.1877	0.2339	0.1781	0.2003
South Tce	King William St	111	0.1903	0.1704	0.2151	0.1895
Grote St	Victoria Sq	116	0.0000	0.1850	0.1896	0.1850
Rundle St	Pulteney St	119	0.1518	0.1274	0.1533	0.0000
Grenfell St	Pulteney St	120	0.1446	0.2186	0.1603	0.1671
Pirie St	Pulteney St	121	0.1451	0.1784	0.1629	0.1624
Flinders St	Pulteney St	122	0.1562	0.2212	0.1683	0.1853
Wakefied St	Pulteney St	123	0.1683	0.1861	0.1698	0.1741
Angas St	Pulteney St	124	0.1489	0.1912	0.1598	0.1719
Carrington St	Pulteney St	125	0.1298	0.1819	0.1580	0.1711
Halifax St	Pulteney St	126	0.1676	0.2047	0.1776	0.1782
Gilles St	Pulteney St	127	0.1642	0.2339	0.1775	0.2027
South Tce	Unley Rd	128	0.1449	0.1870	0.1898	0.1870
Grote St	*Morphett St*	*133*	*0.1697*	*0.1511*	*0.1739*	*0.1777*
Gouger St	Morphett St	134	0.1544	0.1407	0.1947	0.1738
South Tce	Morphett St	135	0.1814	0.1713	0.2457	0.2114
North Tce	Frome Rd	137	0.2043	0.1426	0.2043	0.1268
Rundle St	Frome St	138	0.1865	0.1993	0.2161	0.1717
North Tce	East Tce	139	0.0000	0.1563	0.1551	0.1600
Wakefied St	Hutt St	141	0.1813	0.1954	0.2072	0.1718
North Tce	West Tce	142	0.0000	0.1317	0.1678	0.1814
Currie St	West Tce	143	0.1565	0.1590	0.1565	0.1819
West Tce	Goodwood Rd	145	0.1690	0.1286	0.1730	0.2120
O'connell St	Tynte St	147	0.1504	0.1865	0.1531	0.1684
Tynte St	Lefevre Tce	148	0.1735	0.0000	0.1735	0.1909
O'connell St	Ward St	149	0.1427	0.1664	0.1470	0.1739
O'connell St	Brougham Pl	150	0.1461	0.1794	0.1470	0.1794
King William Rd	Kermode st	151	0.1461	0.1794	0.1395	0.1794
Pirie St	Hutt St	152	0.1813	0.2177	0.2072	0.2108
Grenfell St	Frome St	156	0.1821	0.2130	0.2372	0.1809
Wakefied St	Victoria Sq	157	0.1896	0.1865	0.0000	0.1850

Table XVII: Proportion of total AM and PM peak hour flows of Daily Traffic for CBD intersections (continuation)

INTERSECTION DETAILS			INTERSECTION APPROACH			
STREET1	**STREET2**	**JUNCT_ID**	**North**	**East**	**South**	**West**
South Tce	Hutt St	159	0.1903	0.1516	0.2572	0.1851
Pirie St	Frome St	162	0.1715	0.2166	0.2104	0.1650
Hindley St	Topham St	164	0.1557	0.1148	0.1423	0.1300
Flinders St	Frome St	166	0.2377	0.2355	0.2561	0.1853
Glen Osmond Rd	Hutt Rd	168	0.1999	0.1976	0.1999	0.1976
Wakefied St	Frome St	169	0.2246	0.1954	0.2512	0.1684
Melbourne St	Frome Rd	170	0.2103	0.1731	0.1976	0.1976
Montefiore Rd	Memorial Dr	171	0.1825	0.2047	0.1825	0.1842
Jeffcott St	Ward St	172	0.1886	0.1548	0.1882	0.1720
Halifax St	Hutt St	173	0.1766	0.1797	0.2241	0.1797
Melbourne St	Jerningham St	174	0.1798	0.1776	0.1571	0.1620
Gilbert St	Morphett St	175	0.1814	0.2104	0.1814	0.1827
Franklin St	Pitt St	180	0.0000	0.1932	0.2102	0.1977
Angas St	Hutt St	181	0.1741	0.2308	0.2074	0.2308
Hindley St	West Tce	183	0.1535	0.1503	0.1590	0.0000
Franklin St	West Tce	184	0.1636	0.2087	0.1633	0.0000
Currie St	Gray St	185	0.1200	0.1590	0.1700	0.1590
Sir Edwin Smith Av	Kermode St	187	0.1704	0.0000	0.1704	0.1732
Frome Rd	Victoria Dr	188	0.2099	0.0000	0.2099	0.2051
Angas St	Frome St	191	0.2011	0.1888	0.2387	0.1850
O'connell St	Archer St	192	0.1375	0.1857	0.1467	0.1726
Sturt St	West Tce	194	0.1818	0.1904	0.1817	0.0000
Jeffcott St	Wellington Sq	196	0.2103	0.0000	0.0000	0.2098
Melbourne St	Hackney Rd	197	0.0000	0.1923	0.1736	0.1734
Jeffcott St	Montefiore Hill	198	0.1799	0.1240	0.1799	0.1240
Franklin St	Bentham St	200	0.2102	0.1932	0.0000	0.1977