AN ANALYSIS OF VEHICULAR SPEED CHARACTERISTICS AS A FUNCTION OF STOP SIGN DENSITY

BY

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ABSTRACT

The research is an analysis of vehicular speed characteristics at midpoint between stop signs as a function of stop sign frequency per length of road in an urban setting. The purpose of analysis is to reveal issues that should be considered during the decision-making process regarding stop sign density and its impact on speed.

Previous research with respect to stop signs, vehicular speeds, and driver compliance with stop signs is summarized.

Data collection programs to understand vehicular speeds as a function of stop sign density and to analyse driver compliance with stop signs were designed, developed, and implemented.

The research found that the posted speed limits and the 85th percentile speeds are within 10 km/h of each other for each of the studied cases. Temporal characteristics for mean or 85th percentile vehicular speeds do not change for any of the analysed cases. Furthermore, depending on the study segment, a large proportion of vehicles travel at speeds greater than the posted speed limit of 50 km/h, but most stay within a 10 km/h range. The research found differences in the percentage of vehicles travelling greater than the posted speed limit of 50 km/h based on day of week, but not based on time of day, except for one of the analysed cases. There is no clear relationship between stop sign density and vehicular speeds. However, by removing Gilmore Avenue from the analysis, there is a

trend of increasing speeds at midblock locations when comparing segments with two stop signs per kilometre to segments with greater than two stop signs per kilometre.

The analysis involving driver compliance with stop signs found a large number of violations of stop signs, regardless of the road segment. About one-quarter of drivers comply with stop signs and the remaining three-quarters do not comply with stop signs either because they roll through the intersection or because they do not stop at all (about 6:1).

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1.0 INTRODUCTION

1.1 THE RESEARCH

The research is an analysis of vehicular speed characteristics at midpoint between stop signs as a function of stop sign frequency per length of road in an urban setting. In this research, the term "density" is used to refer to "frequency per length of road". The purpose of analysis is to reveal issues that should be considered during the decision-making process regarding stop sign density and its impact on speed.

1.2 BACKGROUND AND RESEARCH NEED

The installation of traffic control devices started in the early 1900s with the first stop sign being installed in Detroit in 1915 (Hawkins, 1992). The primary function of a stop sign is to assign right-of-way of vehicles at an intersection (Lum, 1983). The Transportation Association of Canada (1998) states "The purpose of a Stop sign (RA-1) is to indicate to drivers that they must stop their vehicles completely before entering the intersection area and must not proceed until it is safe to do so". The Manual of Uniform Traffic Control Devices (MUTCD) and the Manual of Uniform Traffic Control Devices for Canada (MUTCDC) each provide warrant criteria to guide Transportation Engineers as to where it is appropriate to install stop signs. Some jurisdictions have developed their own warrant criteria which are less conservative than the MUTCD (Cottrell, 1996). This is common in residential areas where the MUTCD warrant criteria are difficult to meet due to the low traffic volumes (Cottrell, 1996).

Fatal collisions at stop signs represent 9.5 % of all fatal collisions in the United States (NHTSA, 2004). There were 13,627 motor vehicles involved in fatal collisions at stop signs. Approximately 21 % of drivers failed to stop at the stop sign and approximately 23 % failed to yield right-of-way after stopping at the stop sign. This shows that there are serious safety concerns at stop sign locations.

Public agencies receive many requests for the installation of stop signs to reduce vehicular speeds, reduce cut-through traffic, and/or increase safety at intersections (Upchurch, 1983; Noyes, 1994; Cottrell, 1996). Residents feel safer in communities with stop signs and parents feel their children are protected by stop signs, therefore are safer at stop controlled intersections (Laplante, 1992). Cottrell (1996) states that "All-way, or multiway, stop signs are perhaps the most controversial form of residential traffic control". Upchurch (1983) states that four-way stop control is the most common example of using an unwarranted traffic control device at unsignalised intersections. He also states that stop signs "...are often installed, as the result of political pressure and in violation of the warrants, as residential traffic controls or in the mistaken belief that they will reduce speeds or increase safety." Bretherton (1999) states that when unwarranted stop signs are installed, it is commonly for traffic calming purposes.

Agency websites often state that unwarranted stop signs may create problems at midblock and at intersections as motorists may drive faster between stop signs to make up for lost time and may not comply at the stop sign locations (FHWA, 2004; City of Troy, 2004).

Some studies have found that stop signs are not effective speed control devices (Beaubein, 1976; Chadda, 1983; Beaubein, 1989; Eck, 1988; Noyes, 1994). However, Eck (1988) and Ballard (1990) found that the 85th percentile speeds decreased after the installation of four-way stop control. Many studies have found low driver compliance with stop signs when not required to stop due to minimal cross street traffic (Beaubein, 1976; Smith, 1980; Eck, 1988; Beaubein, 1989; Noyes, 1994; Cottrell, 1996). However, it is not apparent from the literature that research has been done to study vehicular speed characteristics at midpoint between stop signs as a function of stop sign density.

Previous research topics on stop signs include installing unwarranted stop signs as a traffic calming measure and/or as a safety device. Many publications on stop signs were completed in the late 1970s, 1980s and early 1990s. In recent years there has not been much research regarding the impact of stop signs. This research analyses vehicular speed characteristics at midpoint between stop signs as a function of stop sign density in an urban setting. The research also analyses the characteristics of driver compliance with stop signs. The reason for this research is to provide additional information on these speed characteristics and those of driver compliance at stop signs to assist jurisdictions in making decisions involving this issue.

1.3 OBJECTIVES AND SCOPE

The objectives of this research are:

1) To obtain an understanding about the research and background information pertaining to stop signs in an urban area and their impact on traffic operations, safety, and driver compliance with traffic control.

2) To design, develop, and implement a data collection program to understand vehicular speeds as a function of stop sign density along a given road segment.

3) To analyse vehicular speeds and their temporal characteristics as a function of stop sign density.

4) To design, develop, and implement a data collection program to monitor driver compliance at stop signs, and analyse the characteristics of driver compliance with stop signs.

This research is limited to Winnipeg, which represents a mid-size urban area. The purpose of the research is to help decision makers concerning the stop sign issue. It involves both warranted and unwarranted stop signs located in residential areas with a grid land use pattern. The data is collected during dry roadway and weather conditions.

1.4 THESIS ORGANIZATION

Chapter 2 presents a summary of the comprehensive literature review with respect to stop signs, vehicular speeds, and driver compliance with stop signs. The areas of interest were stop signs as a traffic control device, multi-way stop sign warrants, safety issues associated with stop signs, vehicular speeds between stop sign locations, and driver compliance with stop signs.

Chapter 3 discusses the methodology used to design, develop, and implement a data collection program to understand vehicular speeds as a function of stop sign density. The chapter also discusses the design, development, and implementation of the data collection program to analyse driver compliance with stop signs. The data collection programs include selecting appropriate study locations, collecting vehicular speed data and completing field observations of driver compliance with stop signs.

Chapter 4 analyses the characteristics of speed distributions at each location selected for investigation. The chapter also presents the results of the analysis involving driver compliance with stop signs.

Chapter 5 presents findings of the research for each of the following: (1) literature review pertaining to stop signs in urban areas; (2) design, development, and implementation of the data collection programs used in this research; and (3) analysis of vehicular speed characteristics at midpoint between stop signs and driver compliance with stop signs. The chapter also addresses future research opportunities.

1.5 TERMINOLOGY

The following terms are used in this research:

Driver compliance with stop signs: This refers to drivers that completely stop at the stop sign.

Right-of-way: As defined by The Manitoba Highway Traffic Act (2006), this is "where two vehicles enter an intersection from different highways at approximately the same time and there is at the intersection no traffic control device directing the driver of one of the vehicles to yield the right-of-way, the driver of the vehicle on the left shall yield the right-of-way to the vehicle on the right…".

Stop: As defined by The Manitoba Highway Traffic Act (2006),

> ""**stop**", as applied to a vehicle whether occupied or not, means
>
> (a) when required, to cause the vehicle to cease to move, and
>
> (b) when prohibited, to cause the vehicle to cease to move, except when necessary to avoid conflict with other traffic or in compliance with the directions of a peace officer or a traffic control device"

Study segment: This is the total length of roadway being studied for this research. In this research the study length of each study segment is approximately one kilometre.

Stop sign density: This is the frequency of stop signs over a defined distance.

Unwarranted stop signs: Unwarranted stop signs are those installed when the stop sign analysis does not meet the established warrant criteria in the MUTCD or warrant criteria developed by a jurisdiction.

Warranted stop signs: Warranted stop signs are those installed when the stop sign analysis meets the established warrant criteria in the MUTCD or warrant criteria developed by a jurisdiction. Warrant criteria are typically based on vehicular speeds, traffic volumes, vehicular delays, sight lines, and/or collision experience.

2.0 LITERATURE REVIEW

This chapter presents a summary of the comprehensive literature review with respect to stop signs, vehicular speeds, and driver compliance with stop signs. The areas of interest were stop signs as a traffic control device, multi-way stop sign warrants, safety issues associated with stop signs, vehicular speeds between stop sign locations, and driver compliance with stop signs.

2.1 GENERAL DESCRIPTION OF THE SEARCH

A literature review was conducted to gather research and background information pertaining to stop signs. The literature review was completed by searches via the internet, jurisdictions websites, University websites, transportation journals and publications, newspaper articles, discussion group archives, and other literature sources.

The literature review included an extensive search on the internet. The websites that were visited and where searches were conducted include: (1) Transportation Research Board (TRB); (2) Institute of Transportation Engineers (ITE); (3) Virginia Transportation Research Council, (4) Turner-Fairbank Highway Research Center (TFHRC), (5) Australasian Road Safety Research, Policing and Education, (6) Austroads, and (7) Monash University. The Transportation Research Information Services (TRIS) database was also utilized to conduct searches. The areas of interest were stop signs as a traffic control device, multi-way stop sign warrants, safety issues associated with stop signs, vehicular speeds between stop sign locations, and driver compliance with stop signs. The key words and key word combinations used to conduct the search were:

- stop sign
- stop control
- unsignalised/unsignalized
- all way stop control
- driver behaviour
- driver behaviour intersection
- driver behaviour stop sign/control
- traffic control
- stop sign warrants
- school zone (area)
- school zone (area) speed
- driver compliance intersections
- compliance all way stop control
- compliance two way stop control
- driver behaviour rail crossing
- vehicle speed rail crossing

The following sections summarize key findings of the literature pertaining to the effectiveness of stop signs.

2.2 STOP SIGNS AS A TRAFFIC CONTROL DEVICE

Stop signs were first introduced as a traffic control device in the early 1900s. At the time, there was no uniformity with stop sign usage between jurisdictions. The first attempt towards uniformity of signing and marking was in 1922 when three people reviewed signs and markings of several states (Hawkins, 1992). The outcome of their review provided distinctive sign shapes to indicate different danger levels (Hawkins, 1992). One of the shapes chosen to signify an increased level of danger was the octagonal shape for the stop sign because the shape requires a lot of cutting and wastage and would have the fewest installations (Hawkins, 1992). Since the octagonal shape is unique to the stop sign, drivers can identify the sign from approaching the back of the sign (Wikipedia, 2006). To continue with providing uniformity of signing and marking, two national manuals were established (Hawkins, 1992). In 1927, the American Association of State Highway Officials (AASHO) rural signing manual was created for uniformity of signing in rural communities and standardized the stop sign to contain a yellow background with black text (Hawkins, 1992). In 1930, the Manual on Urban Traffic Control Devices was created for uniformity of traffic control devices in urban communities and standardized the stop sign to contain a yellow background with red text (Hawkins, 1992). In 1932, a Joint Committee on Uniform Traffic Control Devices was created to combine the two manuals into one manual of traffic control devices for both rural and urban use (Hawkins, 1992b). This produced the first edition of the Manual of Uniform Traffic Control Devices (MUTCD) in 1935. From 1935 to 1971, there were eight revisions to the stop sign in the MUTCD with a significant revision being in 1954 when the stop sign was changed from a yellow background with black text to a red background with white text (Hawkins, 1992c). This has since remained the standard for the stop sign. The main reason for the change in the stop sign colours was because the red paint was durable and would not fade over time (Hawkins, 1992c). Wikipedia (2006) states that red is used to inform drivers that they have to stop at a traffic signal, thus changing the stop signs to red would unify red as a stop symbol. Canada also created a national manual for uniformity of traffic control devices called the Manual of Uniform Traffic Control Devices for Canada (MUTCDC) in 1959 with the latest edition published in 1998 with subsequent updates to 2002 by the Transportation Association of Canada (TAC).

2.3 MULTI-WAY STOP SIGN WARRANTS

MUTCD (2003) and MUTCDC (1998) established warrants to be used as a guide for installing stop signs. The MUTCDC states "Stop signs should only be used where traffic engineering studies indicate that the usage of Stop signs is warranted." The MUTCDC multi-way stop sign warrants consider such aspects as traffic volumes, vehicular delays, and collision experience. Some jurisdictions have developed their own warrants to follow which are easier to meet than the MUTCD (Cottrell, 1996). This is common for local residential streets where traffic volumes are lower (Cottrell, 1996).

The MUTCDC defines the warrant criteria for multi-way stop control as follows:

> "Multi-way Stop signs may be warranted under one or more of the following conditions:
>
> a) where the traffic volumes on the intersecting roads are approximately equal, and the combined pedestrian and vehicular volumes on the minor road average 200 per hour for an eight hour period;
>
> b) where the average delay to the minor road vehicular traffic entering the intersection exceeds 30 seconds per vehicle during the peak hour;
>
> c) where traffic signals are not warranted, and a collision problem exists, as indicated by five or more reported collisions per year of a type which may be prevented by a multi-way Stop sign installation. Such collisions include right and left turn collisions as well as right angle collisions;
>
> d) as an interim measure prior to the installation of traffic signals; or
>
> e) as an interim measure, for a period of approximately one month prior to switching the stop control from one road to an intersecting road and the subsequent removal of existing Stop signs on the first road."

The City of Winnipeg (2003) Technical Standards and Practices outlines warrant criteria for the installation of multi-way stop control. The City of Winnipeg's Technical Standards and Practices are in draft form and are currently being reviewed and revised. For local/local intersections, multi-way stop control may be installed based on a 70 % petition representing support from residents within a one-block radius from the intersection and when there is no other form of traffic control device within 200 metres of the intersection. For intersections of one or more collector or arterial streets, multi-way stop control may be installed provided that:

> "In the highest 8-hour period, 4,000 vehicles approach the intersection from all directions with at least 1,600 vehicles and pedestrians approaching on the lower volume street; or, there are at least 9 right-angle or left with opposing through collisions reported at the intersection in the most recent 3-year period.
>
> Notwithstanding the above, stop signs should be reviewed in terms of the distance between other stop signs along a route. Additional stop signs should not be installed if there is another traffic control device within 250 metres."

2.4 SAFETY ISSUES ASSOCIATED WITH STOP SIGNS

The National Highway Traffic Safety Administration (NHTSA, 2004) analysed the 1999 and 2000 Fatality Analysis Reporting System database to determine the percentage of fatal collisions due to stop sign violations in the United States. Fatal collisions at stop signs represented 9.5 % of all fatal collisions in the United States. Violations were classified into two categories, failure to obey and failure to yield. The report defined "failure to obey" as collisions which occurred because a driver ran the stop sign. "Failure to yield" represents collisions where the driver failed to yield the right-of-way after stopping at the stop sign. The study found that there were 13,627 motor vehicles involved in fatal collisions at stop signs in the United States. Approximately 21 % of drivers failed to stop at the stop sign and approximately 23 % failed to yield right-of-way after stopping at the stop sign.

The State of Minnesota examined right angle collisions at rural two-way stop controlled intersections to determine if these collisions were due to drivers violating the stop sign on the minor road (Preston, 2003). Right angle collisions represent 36 % of all collisions at stop signs in Minnesota and are also the most common and most severe type of collision at an intersection. Right angle collisions at two-way stop controlled intersections account for 48 % of collisions involving property damage, 62 % of collisions involving serious injuries, and 71 % of collisions involving fatalities. The Police reports revealed that 57 % of right angle collisions were due to drivers proceeding after stopping at the stop sign, 26 % were due to drivers running stop signs, and 17 % were unknown. The study also revealed that right angle collisions caused by vehicles running stop signs are more severe than the stop and proceed collisions.

Retting (2003) analysed motor-vehicle collisions at stop signs in four U.S. cities (Germantown, TN; Oxnard, CA; Springfield, NO; Westfield, NJ) to gain a better understanding of collisions at stop signs. The study examined 1,788 police reports involving motor vehicle collisions during 1996-2000 to determine the number of collisions due to stop sign violations. The study defined a stop sign violation as:

> "A vehicle required to stop and yield does not do so and collides with other vehicle".

The results showed that stop sign violations accounted for 70 % of all collisions at two-way stop controlled intersections, with right angle collisions being cited the most. When examining collisions not involving stop sign violations, rear-end collisions were most common (12 % of collisions). Approximately 66 % of all stop sign violation collisions involved drivers who said they had first come to a stop but were unable to, or failed to see approaching traffic. Retting noted that some drivers that violated the stop sign might not have admitted the truth to the police officers. Approximately 12 % of collisions involved drivers who did not stop.

Kentucky Transportation Center examined the number of collisions in Kentucky which involved drivers violating stop signs from 1998 to 2002 (KTC, 2003). The study found that 0.70 % of all collisions on public highways in Kentucky involved drivers violating stop signs and 1.46 % (55 collisions) of all fatal collisions on public highways in Kentucky involved drivers violating stop signs. Approximately 46 % of collisions resulted in injury due to stop sign violations.

Lovell (1986) examined the safety effect from converting two-way stop control to all-way stop control at both urban and rural intersections. Lovell found that the previous studies reported a decrease in collisions when converting two-way to four-way stop control. However, the studies were completed at high collision intersections, which may have caused the data to be biased. Lovell wanted to determine the unbiased safety effect of the conversion. The study concluded that "it appears that the conversion to all-way stop control may be expected to reduce total accidents by 47 percent with right-angle and injury accidents dropping by 72 and 71 percent, respectively."

The Michigan Department of Transportation evaluated collision history at ten low volume, high speed, rural intersections, which were converted from two-way to four-way stop control (Briglia, 1982; ITE 1984). Low volume was defined as less than 13,000 vehicles per day approach volumes. The ten intersections were chosen for conversion from two-way to four-way stop control in an attempt to reduce the number of right angle collisions occurring at the two-way stop controlled intersections. The study reviewed three year collision data for eight of the intersections and two year collision data for two of the intersections before and after the conversion. The three year before-after collision data at eight intersections showed percent reductions for all types of collisions. Right angle collisions decreased by 75 % (102 collisions) while rear-end, left-turn, right-turn, and other decreased by 46.3 % (19 collisions), 47.1 % (8 collisions), 33.3 % (1 collision), and 33.3 % (11 collisions), respectively. The reductions are statistically significant at the 97.5 % confidence level. The two year before-after collision data at two intersections showed percent reductions for right angle collisions (80 % or 8 collisions), rear-end (66.7 % or 2 collisions), and other (59.4 % or 19 collisions). The left-turn collisions increased from one collision to two collisions and the right-turn collisions did not increase. The two year before-after collision reductions were not tested for significance because of the low number of collisions. The total collisions decreased by 58 % from converting two-way stop controlled intersections to four-way stop controlled intersections. There was a total reduction of 169 collisions, which consisted of a reduction of 77 property damage collisions, 82 injury collisions, and 10 fatal collisions.

2.5 VEHICULAR SPEEDS BETWEEN STOP SIGNS

No recent research can be found on studying vehicular speeds between stop signs. Agency websites often site that unwarranted stop signs may create problems as motorists may drive faster between stop signs to make up for lost time (FHWA, 2004; City of Troy, 2004). Some studies have found that stop signs are not effective speed control devices (Beaubein, 1976; Eck, 1988; Beaubein, 1989; Noyes, 1994). However, some research (Eck, 1988; Ballard, 1990) has found that the 85th percentile speeds decreased after the installation of four-way stop control.

The City of Troy conducted before-after speed studies on four residential streets (Beaubein, 1976). All-way stop control was installed at one intersection on each of the three streets (Anvil Drive, Niagara Drive, Crimson Street) due to a perceived speeding problem by residents. All-way stop control was temporarily removed at an intersection on the fourth street (Robinwood Street). The stop signs were installed on Robinwood Street in 1964 as a response to a child fatality. The child was struck by a vehicle approximately 150 feet (45.7 metres) from the stop sign. The City of Troy completed "after" studies 30 days after the installation/removal of the stop signs. On Anvil Drive, the before-after studies did not show a significant difference in average speeds due to the stop signs (without stop signs 24.1 mph (38.8 km/h); with stop signs 24.6 mph (39.6 km/h)). On Niagara Drive, the before-after studies indicated that the stop signs were not effective in reducing average speeds (without stop signs 23.8 mph (38.3 km/h); with stop signs 25.2 mph (40.6 km/h)). On Crimson Street, four spot speed studies were completed. The studies showed no significant difference in average speeds. The average speed results for the four spot speed studies on Crimson Street were 23.6 mph (38.0 km/h) without stop signs and 24.7 mph (39.8 km/h) with stop signs. Stop signs were removed temporarily on Robinwood Street. The speed studies showed no significant difference in speeds after the stop signs were removed (with stop signs 24.4 mph (39.3 km/h); without stop signs 23.4 mph (37.7 km/h)). The City of Troy concluded that:

> "stop signs are not effective in controlling speeds in residential areas. The difference in average speeds is not significant after installation of the stop signs, but the tendency is for a slight increase in speeds, possibly because motorists are tying to make up for lost time after passing the sign. The same tendency occurs in the reverse when the stop sign which have been in place for many years are removed. After removal, there was no significant change in speeds, but the speeds were slightly lower without the stop signs".

In 1986, the City of Troy completed speed studies at the same locations as the 1975 study to compare speed data from 1975 to 1986 (Beaubein, 1989). In each case, the low and average speeds were higher in 1986 than in 1975, but the differences may not be statistically significant. The study concluded that over time, stop signs do not become effective in controlling vehicular speeds.

Marconi (1977) evaluated the effectiveness of speed control measures, such as stop signs, in residential areas. Stop signs were installed at three locations. The study found stop signs to be extremely effective in reducing the 95th percentile speeds by 16 to 20 mph (25.7 to 32.2 km/h) at the stop controlled intersections. The area of influence of reducing vehicular speeds was found to be approximately 200 feet (61 metres) before and approximately 100 feet (30.5 metres) after the stop sign, resulting in a total area of influence of approximately 300 feet (91.5 metres). Vehicles were found to slow down at a fairly uniform rate when approaching the intersection, but after the intersection, most drivers were close to their highest speeds within 100 feet (30.5 metres) of the intersection.

Eck (1988) conducted a study to evaluate two-way versus four-way stop sign control at low volume intersections in residential areas (Eck, 1988). This study defined low volume as the Average Daily Traffic less than 400 vehicles per day. Spot speed studies were conducted on all four approaches to the intersection, at approximately a point midblock between the next stop sign controlled intersection. The average mean speeds decreased from 23 mph (37.0 km/h) to 21.9 mph (35.2 km/h) on the streets with higher traffic volumes after the installation of four-way stop control. The 85th percentile speeds decreased by an average of 2.3 mph (3.7 km/h) on the streets with higher traffic volumes after installation of four-way stop control. The study concluded that "mean midblock speeds did not change significantly between the two-way and four-way stop conditions. However, use of four-way stop control resulted in a lower 85th percentile speed and a higher percentage of vehicles traveling within the 10-mph pace".

San Antonio completed a study on treatments, such as stop signs, to control speeds on residential collector streets (Ballard, 1990). Two cases were studied; no stop sign control and stop sign control. The study found higher speeds at locations where there is no stop sign control compared to locations where there is stop sign control. Spot speed studies were completed at four locations (two locations approaching an existing stop sign and two locations after an existing stop sign). The average mean speed and average 85th percentile speed was found to be 29.6 mph (47.6 km/h) and 34.1 mph (54.9 km/h), respectively. Spot speed studies completed at two locations which were not stop sign controlled showed higher average mean and average 85th percentile speeds. The average mean speed and average 85th percentile speed was found to be 33.6 mph (54.1 m/h) and

39.1 mph (62.9 km/h), respectively. The study also measured speeds within 300 feet (91.4 metres) of the intersection to determine the area influenced by the stop sign. Spot speed studies were completed at 100 feet (30.5 metres) intervals before and after the intersection. Seven months after the installation of the stop sign, the 85th percentile speed at the six sites showed a reduction in speeds, 300 feet (91.4 metres) from the stop sign. Speeds were measured at two intersections on another street 500 feet (152.4 metres) from the stop signs. Seven months after the installation of the two stop signs, the 85th percentile speed showed a reduction in speeds, 500 feet (152.4 metres) from the stop signs.

The City of Boulder measured vehicular speeds approximately 500 feet (152.4 metres) upstream and downstream of four 4-way and two 3-way stop controlled intersections (Noyes, 1994). The study found that mean speeds and average 85th percentile speeds were above the posted speed limit. The study indicated that the measured speeds are comparable or higher than speeds on other residential streets in Boulder.

Clark (2000) compared the effectiveness of reducing vehicular speeds by using all-way stop control or speed humps. For the purposes of this paper, only the results of all-way stop control are discussed. The study collected speed data before and after all-way stop control was installed. The study concluded that all-way stop control has a very limited area of influence, approximately 100 feet (30.5 metres) before and after the stop sign, resulting in a total area of influence of 200 feet (61 metres). The installation of stop signs does not appear to influence vehicular speeds beyond the 200 feet (61 metres) area of influence. The study also found that the 85^{th} percentile speed through an unwarranted stop sign was approximately 5 to 7 mph (8.1 to 11.3 km/h).

2.6 DRIVER COMPLIANCE WITH STOP SIGNS

Many studies have found that the percentage of driver compliance with stop signs is low (Beaubein, 1976; Smith, 1980; Eck, 1988; Beaubein, 1989; Noyes, 1994; Cottrell, 1996; NSKC, 2003). Driver compliance at unwarranted stop signs is poor because drivers feel the stop signs are not necessary since they rarely see cross street traffic (Chadda, 1983; Cottrell, 1996; Noyes, 1994). Stop signs provide pedestrians with a false sense of security that the vehicle will stop, thus reducing pedestrian safety (Chadda, 1983; Noyes, 1994).

In 1975, the City of Troy studied driver compliance with stop signs at four intersections and found that 73 % of vehicles were non-compliant (Beaubein, 1976). Three of the same intersections were studied ten years later to compare the results of driver compliance with stop signs (Beaubein, 1989). In 1985, the City of Troy found that 83 % of drivers were non-compliant at stop signs. The results show a 10 % increase in violating the stop signs over ten years.

Eck (1988) analysed driver compliance characteristics before and after converting an intersection from two-way to four-way stop control. The study found that approximately 80% of drivers were non-compliant at stop signs in both conditions. The study also found that the percent of drivers making a voluntary full stop and the percent of drivers stopped by traffic was approximately equal before and after converting the intersection. Approximately 15.7 % of drivers voluntarily stopped at the stop signs and approximately 3.5 % of drivers were stopped by traffic. The percent of drivers that practically stopped at the stop signs decreased from 65.7 % to 55.8 % and the percent of drivers not stopping at the stop signs increased from 14.1 % to 25.1 %, after converting the intersection from two-way to four-way stop control.

Smith (1980) summarized other research which showed that when vehicles are not required to stop by cross street traffic, only 5 % to 20 % percent of drivers will come to a complete stop; 40 % to 60 % will come to a rolling stop below 5 mph (8 km/h), and 20 % to 40 % will drive through at speeds higher than 5 mph (8 km/h).

Todd (1993) discussed findings of another report as follows:

> "Lum and Stockton, in a report on stop and yield signs at low-volume intersections, found that drivers slowed to whatever speed was required to evaluate the safety of entering the intersection before choosing their course of action, regardless of sight distance or type of control. Most slowed to 5 mph or less. Of the drivers who were not stopped by the presence of priority vehicles, only 19 percent stopped voluntarily at stop signs."

Boulder, Colorado studied driver compliance with stop signs at nine 4-way stop controlled intersections and found that 77 % of drivers were non-compliant (Noyes, 1994). The study completed 900 observations and found that 23 % of drivers made a complete stop, 73 % of drivers rolled through the stop sign, and 4 % of drivers ran the stop sign. The City of Boulder also studied driver compliance with stop signs at four 3-way stop controlled intersections and found that 93 % of drivers were non-compliant. The study completed 350 observations and found that 7 % of drivers made a complete stop, 82 % of drivers rolled through the stop sign, and 11 % of drivers ran the stop sign.

Cottrell (1996) summarized studies on driver compliance with stop signs. North Carolina found that 72 % of drivers were non-compliant at stop signs located on the side street (nine intersections were studied). The Federal Highway Administration studied driver compliance with stop signs at 142 intersections and found that 68 % of drivers were non-compliant. The Institute of Transportation Engineers reported that when vehicles are not required to stop as a result of minimal cross street traffic, 80 % to 95 % of drivers are non-compliant at the stop sign. A Cupertino and San Jose study found that the cross street traffic volume substantially influences the percent of traffic that are compliant at the stop sign. Three all-way stop control intersections were studied and the intersection with the highest traffic volumes on the side street showed the lowest percent of drivers that ran the stop sign (12 %). The intersection with the lowest traffic volumes on the side street showed the highest percent of drivers that ran the stop sign (43 %). The study also showed that between 46 % to 59 % of drivers rolled through the stop sign.

The National Safe Kids Campaign (NSKC, 2003) reported that drivers also violate stop signs when children are present. They reported that 45 % of drivers violated the stop sign, 32 % of drivers violated the stop sign when children were present, 47 % of drivers violated the stop sign when no pedestrians were present, 24 % of drivers violated the stop sign when pedestrians were crossing, and 36 % of drivers violated the stop sign when pedestrians were waiting to cross.

2.7 SUMMARY COMMENTS

There has been little recent research regarding the impact of stop signs. The areas of interest of the literature review were stop signs as a traffic control device, multi-way stop sign warrants, safety issues associated with stop signs, vehicular speeds between stop sign locations, and driver compliance with stop signs. The following is a summary of the research found during the literature review:

- The first edition of the Manual of Uniform Traffic Control Devices (MUTCD) was completed in 1935 to standardize traffic control devices in urban and rural areas. The stop sign colour containing a red background with white text was adopted in the 1954 edition of the MUTCD and has since remained as the standard for the stop sign. Canada created the Manual of Uniform Traffic Control Devices for Canada (MUTCDC) in 1959.

- Upchurch (1983) stated that four-way stop control is the most common example of using an unwarranted traffic control device at unsignalised intersections. "They are often installed, as the result of political pressure and in violation of the warrants, as residential traffic controls or in the mistaken belief that they will reduce speeds or increase safety."

- MUTCD (2003) and MUTCDC (1998) have established warrant criteria to be used as a guide for installing stop signs. The MUTCDC states "Stop signs should only be used where traffic engineering studies indicate that the usage of Stop signs is warranted. These studies should consider such aspects as traffic speeds, traffic volumes, sight lines, and collision experience."

- Even though studies show a low percentage of driver compliance at stop signs, some studies have found a decrease in collisions by converting an intersection from two-way to four-way stop control (Briglia, 1982; ITE, 1984; Lovell, 1986).

- Studies estimated the percentage of collisions due to stop sign violations, as summarized below:

- 21 % and 23 % of fatal collisions at stop signs in the United States failed to obey the stop sign and failed to yield right-of-way after stopping at the stop sign, respectively (NHTSA, 2004);

- 26 % of right angle collisions were due to drivers running the stop sign (Preston, 2003);

- 70 % of all collisions at two-way stop controlled intersections in four U.S. cities involved a driver that violated the stop sign (Retting, 2003); and

- 0.7 % of all collisions on public highways in Kentucky involved drivers that violated stop signs and 1.46 % of all fatal collisions on public highways in Kentucky involved drivers that violated stop signs (KTC, 2003).

- Some research found that stop signs do not effectively reduce speeds (Beaubein, 1976; Eck, 1988; Beaubein, 1989; Noyes, 1994). However, research also found a decrease of 85th percentile speeds between stop signs (Eck, 1988; Ballard, 1990).

- Research shows driver compliance with stop signs varies between 5 % to 32 % (Beaubein, 1976; Smith, 1980; Eck, 1988; Beaubein, 1989; Noyes, 1994; Cottrell, 1996).

- The National Safe Kids Campaign (2003) reported that 45 % of drivers violated the stop sign, 32 % of drivers violate stop signs when children were present, 47 % of drivers violated the stop sign when no pedestrians were present, 24 % of drivers violated the stop sign when pedestrians were crossing, and 36 % of drivers violated the stop sign when pedestrians were waiting to cross.

- Driver compliance at unwarranted stop signs is poor because drivers feel the stop signs are not necessary since they rarely see cross street traffic (Chadda, 1983; Cottrell, 1996; Noyes, 1994). Stop signs provide pedestrians with a false sense of security that vehicles will stop, thus reducing pedestrian safety (Chadda, 1983; Noyes, 1994).

- Other concerns associated with unwarranted stop signs include increasing enforcement responsibilities, vehicle operating costs, emissions to the environment, and noise pollution (Noyes, 1994; Bretherton, 1999).

Table 2.1 summarizes the literature review findings in a tabular format.

Table 2.1: Summary of the Literature Review

Research	Year	Locale	Findings
An Evaluation of 4-Way Stop Sign Control; 4-Way Stop Signs Cut Accident Rate 58% at Rural Intersections	1982; 1984	Michigan	Collisions decreased from converting intersections from 2-way to 4-way stop control
The Safety Effect of Conversion to All-Way Stop Control	1986	San Francisco; Philadelphia; Michigan; Toronto	
Analysis of Fatal Crashes Due to Signal and Stop Sign Violations	2004	United States	21% and 23 % of fatal collisions at stop signs failed to obey the stop sign and failed to yield right-of-way, respectively
Reducing Crashes at Rural Thru-STOP Controlled Intersections	2003	Minnesota	26 % of right angle collisions were due to drivers running the stop sign
Analysis of Motor-Vehicle Crashes at Stop Signs in Four U.S. Cities	2003	Germantown; Oxnard; Springfield; Westfield	70 % of all collisions at 2-way stop controlled intersections involved a driver that violated the stop sign
Stop Signs for Speed Control	1976	City of Troy	Stop signs do not effectively reduce speeds
Field Evaluation of Two-Way Versus Four-Way Stop Sign Control at Low-Volume Intersections in Rural Areas	1988	West Virginia	
Controlling Speeds on Residential Streets	1989	City of Troy	
Responding to Citizen Requests for Multi Way Stop	1994	City of Boulder	
Efforts to Control Speeds on Residential Collector Streets	1990	San Antonio	85th percentile speeds decreased between stop signs
Stop Signs for Speed Control	1976	City of Troy	Driver compliance with stop signs varies between 5 % to 32 %
Controlling Speeds on Residential Streets	1989	City of Troy	
Responding to Citizen Requests for Multi Way Stop	1994	City of Boulder	
Using All-Way Stop Control for Residential Traffic Management	1996	various	

3.0 DESIGN, DEVELOPMENT, AND IMPLEMENTATION OF THE DATA COLLECTION PROGRAMS

This chapter discusses the methodology used to design, develop, and implement a data collection program to understand vehicular speeds as a function of stop sign density. The chapter also discusses the design, development, and implementation of the data collection program to analyse driver compliance with stop signs. The data collection programs include selecting appropriate study locations, collecting vehicular speed data and completing field observations of driver compliance with stop signs.

The methodology used for both data collection aspects of the research (speed data and compliance with stop signs) consisted of the following:

1. site selection
2. collection of vehicular speed data
3. collection of driver compliance with stop signs data

3.1 SITE SELECTION

The selection of sites for the data collection process was a critical aspect of this research. It was important to have a good cross-section of different geographic areas within Winnipeg while keeping road characteristics constant.

Because previous research (Pronk, 1998) has found that a person's socio-economic status can be linked to their driving habits, site selection also involved the use of Statistics Canada Census data (Statistics Canada, 2001) to identify locations with varying socio-economic characteristics.

The site selection also considered the type of network design – grid pattern versus curvilinear pattern. Residential streets are typically laid out in either a grid pattern design or a curvilinear design. Figure 3.1 shows an example of a grid pattern roadway design and a curvilinear pattern roadway design. For the purposes of this research, only areas containing grid pattern roadway network designs are considered.

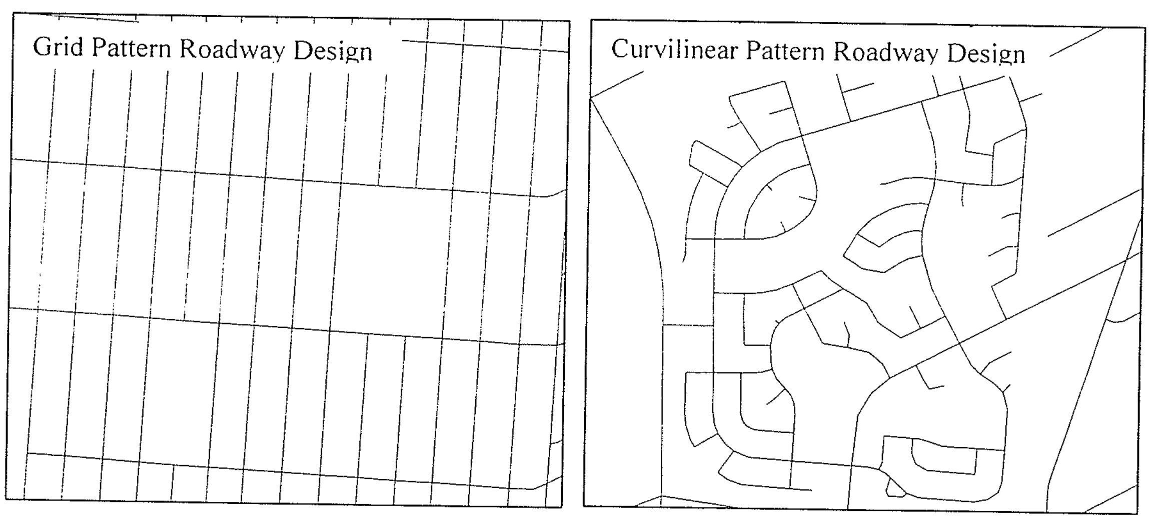

Figure 3.1: Typical Roadway Network Designs

Based on these considerations, a total of eight street segments were selected for analysis. These eight segments are located in the north-east and west areas of the city (four in each area). Studying four street segments per area provides a range of various stop sign densities and provides some degree of generality in terms of the selection criteria and driving task.

This research studies four cases of stop sign densities: two stop signs per kilometre, three stop signs per kilometre, four stop signs per kilometre, and five stop signs per kilometre. It was desired to study as many densities as possible. Four densities were chosen because it was not possible to find five densities (i.e. six stop signs per kilometre). These densities were chosen to determine differences in driver compliance from driving a segment with only a stop sign at each end point (i.e. two stop signs per kilometre) to driving a segment with a total of five stop signs including the end points (i.e. five stop signs per kilometre). The City of Winnipeg traffic regulation database (City of Winnipeg, 2005) was utilised together with field observations to determine the location of the existing stop signs.

Published research was consulted to determine if there is any impact of driver compliance during wet or dry weather and/or roadway conditions. The Federal Highway Administration (1998) reviewed research related to speed and found that weather conditions (i.e. reduced visibility and extreme weather conditions) influenced vehicular speeds; however wet roadway conditions did not influence vehicular speeds. Olson (FHWA, 1998) compared vehicular speeds during daylight hours on dry and wet pavements at 22 sites in Illinois. The study did not find any practical differences in speeds. The maximum difference is speed was less than 2.5 mph (4 km/h). Similarly, Lamm (FHWA, 1998) found no differences in vehicular speeds on dry and wet pavements for eleven curves studied on two-lane rural roads in New York. For this research, data was collected during dry weather and roadway conditions as possible.

3.2 CRITERIA FOR SELECTING STUDY SEGMENTS

The criteria used to select the study segments are: roadway classification, speed limit on roadway, study segment distance, traffic control at end points, roadway cross-section, presence of traffic calming features, presence of school and playground areas, and presence of traffic signals or at-grade rail/road crossings. The following discusses the criteria used to select the study segments.

3.2.1 Roadway Classification

Streets in Winnipeg can be classified as local, collector, or arterial. The primary function of a local residential street is to provide land access (ITE, 1999). Local residential streets typically have narrower pavement widths and on-street parking is common, which further reduces the roadway width. The primary function of a collector street is to provide traffic movement and land access (ITE, 1999). Traffic is collected and distributed between local residential streets and other collector or arterial streets. Collector streets typically have wider pavement widths than local streets. The primary function of an arterial street is to move traffic (ITE, 1999). Arterial streets typically have more lanes, higher speed limits, and higher traffic volumes than local and collector streets. Typically arterial streets do not contain intersection stop sign control and are not located within residential areas.

FHWA (1998) states that cross section elements such as roadway width and number of lanes have a significant influence on vehicle speed.

For this research each study segment was located on a residential local street, as outlined in the City of Winnipeg's "Transportation Standards Manual" (City of Winnipeg, 1991). Residential local streets were selected since stop signs are commonly used on these streets. The speed limit on all selected streets is 50 km/h.

3.2.2 Study Segment Distance

The length for each study segment is approximately equal. For the purposes of this research, the total segment length for each location is approximately one kilometre.

3.2.3 Traffic Control at End Points

Each study segment has the same form of traffic control at each end point. For this research, all locations have a stop sign at each end point. This defines the beginning and end of the study segments.

3.2.4 Roadway Cross-Section

Study segments contain the same roadway cross-section. TAC (1999) classifies typical cross-sections for local streets as rural undivided and urban undivided. FHWA (1998) states that roadway cross-section elements significantly influence vehicular speeds. For this research, an urban cross-section consisting of a two-lane undivided concrete roadway with a curb and gutter are used in the selection criteria. A rural cross-section contains a two-lane undivided gravel roadway with ditches on each side.

3.2.5 Traffic Calming

Study segments do not contain any traffic calming measures. Traffic Calming is defined by TAC (1998) as "the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for non-motorized street users". Some examples of traffic calming measures include speed humps, raised cross-walks, and traffic circles. Ewing (1999) and TAC (1998) show average speed reductions in 85th percentile speeds for streets containing speed humps of 12.4 km/h (7.7 mph) and 14.5 km/h (9.0 mph), respectively. Since traffic calming measures may influence vehicular speeds, streets containing traffic calming measures are not part of this research.

3.2.6 School and Playground Areas

Where possible, school and playground areas are avoided for the selection of study segments. School and playground areas are locations where drivers can expect children to be present at or near the roadway. Advanced warning signs (school area or playground signs) are used to identify the areas. The MUTCDC (1998) states "Where a school abuts a road, it is advisable to provide advance warning to the driver approaching an area where children walk along or may cross the road. In these circumstances, the driver is required to exercise caution in proceeding through these areas". Osmers (2001) found that drivers reduced their speeds within school areas where children were present. This research uses, to the extent possible, streets without school and playground areas. However, there are four segments where this criterion could not be met.

3.2.7 Other

Roadway segments containing traffic signals or at-grade rail/road crossings were avoided for consistency in the study segments.

Table 3.1 summarizes the previously discussed selection criteria.

Table 3.1: Summary of Selection Criteria for Study Segments

Roadway network design	Grid pattern
Number of streets selected	Eight
Stop sign density	Two, three, four, five
Roadway classification	Local
Speed limit	50 km/h
Study segment distance	Approximately 1.0 km
Traffic control at end points	Stop signs
Roadway cross-section	Two-lane, undivided, curb and gutter
Traffic calming	No
School and playground areas	Avoid if possible
Traffic signals	No
At-grade rail/road crossings	No

3.2.8 Selected Study Segments

The selected study segments are:

1) Fleet Avenue between Lindsay Street and Elm Street;

2) Gilmore Avenue between Rothesay Street and Raleigh Street;

3) Mathers Avenue between Lindsay Street and Waverley Street;

4) Brazier Street between Kimberly Avenue and McLeod Avenue;

5) Cuthbertson Avenue between Shaftesbury Boulevard and Southport Boulevard;

6) Roch Street between Kimberly Avenue and McLeod Avenue;

7) Betsworth Avenue between Cullen Drive and Municipal Road; and

8) Louelda Street between Kimberly Avenue and McLeod Avenue.

Figure 3.2 shows the selected study segments for this research. Figure 3.3a and Figure 3.3b shows the stop sign locations on each study segment, and Table 3.2 lists the location of stop signs for each study segment.

The following sections provide a description of each study segment.

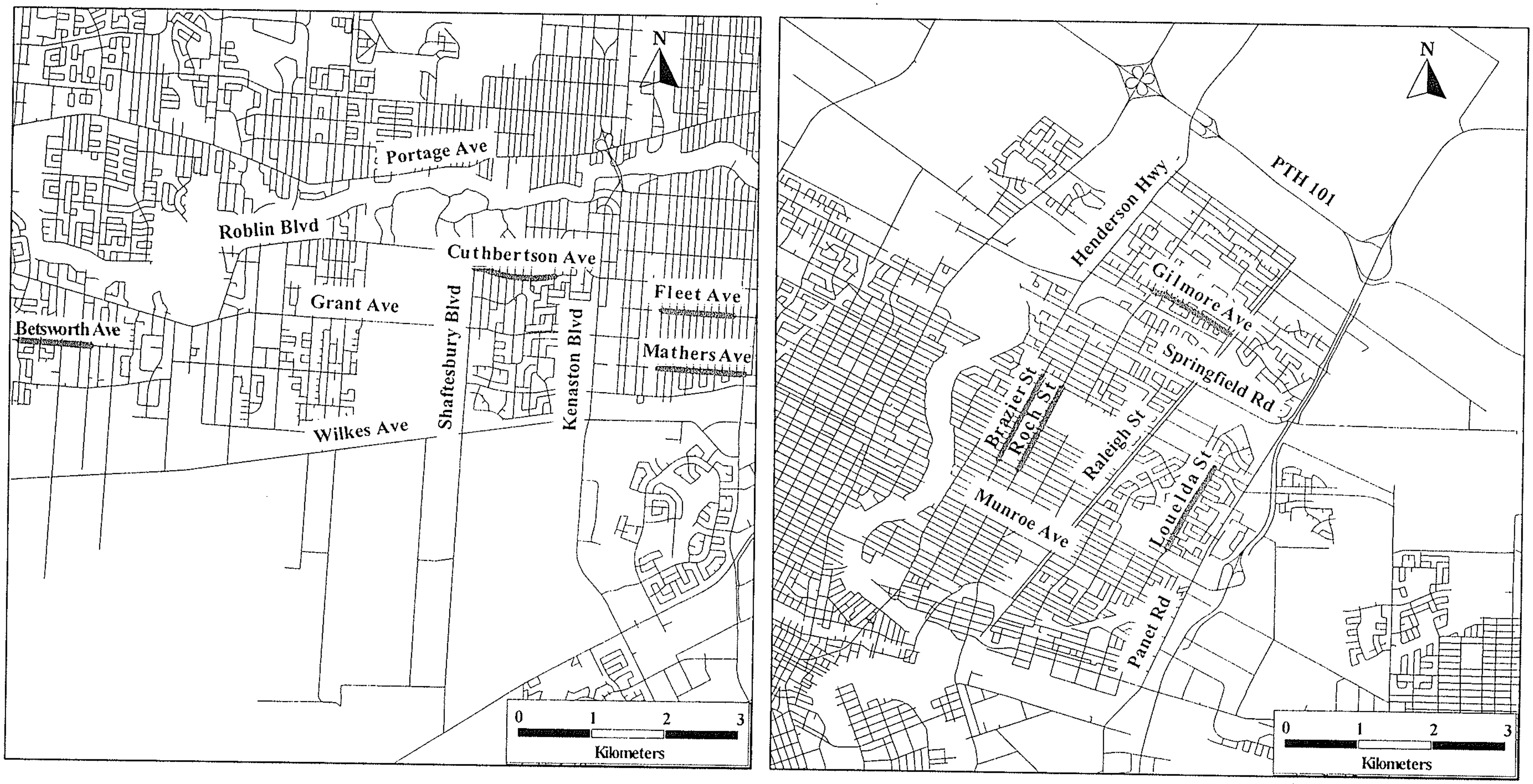

Figure 3.2: Study Segments

Figure 3.3a: Stop Sign Locations

Figure 3.3b: Stop Sign Locations

Table 3.2: Stop Sign Locations

Study Segment	Stop Sign Locations
Fleet Ave	Lindsay St
	Elm St
Gilmore Ave	Rothesay St
	Raleigh St
Mathers Ave	Lindsay St
	Ash St
	Waverley St
Brazier St	Kimberly Ave
	Leighton Ave
	McLeod Ave
Cuthbertson Ave	Shaftesbury Blvd
	Boreham Blvd
	Lamont Blvd
	Southport Blvd
Roch St	Kimberly Ave
	Linden Ave
	Leighton Ave
	McLeod Ave
Betsworth Ave	Cullen Dr
	Buckle Dr/Norlorne Dr
	Berkley St
	Charleswood Rd
	Municipal Rd
Louelda St	Kimberly Ave
	Green Valley Bay/Treger Bay
	Antrim Rd
	Tu-pelo Ave
	McLeod Ave

Fleet Avenue

Fleet Avenue is a local street located in the west side of Winnipeg. It has an average weekday traffic volume of 1,900 vehicles per day between Queenston Street and Niagara Street. Figure 3.4 shows the typical cross-section of this study segment. This is one of the study segments with two stop signs per kilometre.

Figure 3.4: Typical Cross-Section of Fleet Avenue, facing East

Gilmore Avenue

Gilmore Avenue is a local street located in the north-east side of Winnipeg. It has an average weekday traffic volume of 4,000 vehicles per day between Evenlea Walk (east leg) and Greenlea Cove (east leg). Gilmore Avenue functions in part as a collector due to its location within the neighbourhood. Figure 3.5 shows the typical cross-section of this study segment. This is the second study segment with two stop signs per kilometre.

Figure 3.5: Typical Cross-Section of Gilmore Avenue, facing East

Mathers Avenue

Mathers Avenue is a local street located in the west side of the city. It has an average weekday traffic volume of 1,300 vehicles per day between Brock Street and Queenston Street and 1,700 vehicles per day between Mathers Bay East and Mathers Bay East. Figure 3.6 shows a typical cross-section of this study segment. This is one of the two study segments with three stop signs per kilometre.

Brazier Street

Brazier Street is a local street located in the north-east side of the city. It has an average weekday traffic volume of 3,900 vehicles per day between Hazeldell Avenue and Linden Avenue, 4,900 vehicles per day between Dunbeath Avenue and Colvin Avenue. Brazier Street functions in part as a collector due to its location within the neighbourhood. Figure 3.7 shows a typical cross-section of this study segment. This is the second study segment with three stop signs per kilometre.

Figure 3.6: Typical Cross-Section of Mathers Avenue, facing West

Figure 3.7: Typical Cross-Section of Brazier Street, facing North

Cuthbertson Avenue

Cuthbertson Avenue is a local street located in the west side of the city. It has an average weekday traffic volume of 260 vehicles per day between Bower Boulevard and Laidlaw Boulevard, 435 vehicles per day between Kelvin Boulevard and Hosmer Boulevard, and

630 vehicles per day between Lamont Boulevard and Southport Boulevard. Figure 3.8 shows the typical cross-section of this study segment. This is one of the study segments with four stop signs per kilometre.

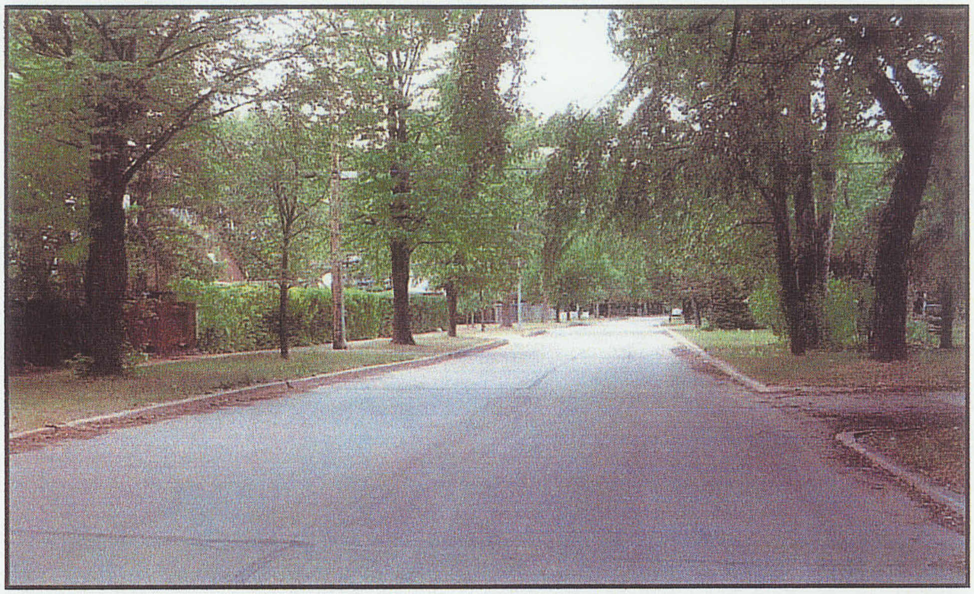

Figure 3.8: Typical Cross-Section of Cuthbertson Avenue, facing West

Roch Street

Roch Street is a local street located in the north-east side of the city. It has an average weekday traffic volume of 3,100 vehicles per day between Dunrobin Avenue and Oakview Avenue; 3,000 vehicles per day between Greene Avenue and Roberta Avenue; and 4,500 vehicles per day between Dunbeath Avenue and Colvin Avenue. Roch Street functions in part as a collector due to its location within the neighbourhood. Figure 3.9 shows the typical cross-section of this study segment. This is the second study segment with four stop signs per kilometre.

Figure 3.9: Typical Cross-Section of Roch Street, facing North

Betsworth Avenue

Betsworth Avenue is a local street located in the west side of Winnipeg. It has an average weekday traffic volume of approximately 1,500 vehicles per day between Cullen Drive and Eager Crescent; 1,370 vehicles per day between Buckle Drive and Norlorne Drive (east leg); 940 vehicles per day between Charleswood Road and Berkley Street; and 920 vehicles per day between Berkley Street and Municipal Road. Figure 3.10a and Figure 3.10b shows the typical urban cross-section and rural cross-section of this study segment, respectively. This is one of the study segments with five stop signs per kilometre.

Figure 3.10a: Typical Urban Cross-Section of Betsworth Avenue, facing West

Figure 3.10b: Typical Rural Cross-Section of Betsworth Avenue, facing West

Louelda Street

Louelda Street is a local street located in the north-east side of Winnipeg. It has an average weekday traffic volume of approximately 2,500 vehicles per day throughout the study segment length. Louelda Street functions in part as a collector due to its location within the neighbourhood. Figure 3.11 shows a typical cross-section of this study segment. This is the second study segment with five stop signs per kilometre.

Figure 3.11: Typical Cross-Section of Louelda Street, facing North

Table 3.3 lists the selected study segments and their characteristics. The column containing the number of stop signs includes the stop signs at the end points.

Four of the study segments contain either school or playground area signs. It would be difficult to avoid school and playground areas as they are typically constructed along local streets and collectors in Winnipeg.

Betsworth Avenue between Charleswood Road and Municipal Road contains a rural undivided cross-section. This type of cross-section contains a two lane undivided gravel roadway with ditches on each side.

Even though some of the streets are functioning as a collector due to their location within the neighbourhood, for the purposes of this research, all study segments will be considered local streets.

Table 3.3: Study Segments

Road	Limits	Number of Stop Signs	Distance (m)	Density (stop signs/km)	All Criteria Met
Fleet Ave	Lindsay St and Elm St	2	960	2.1	y*
Gilmore Ave	Rothesay St and Raleigh St	2	1200	1.7	y*
Mathers Ave	Lindsay St and Waverley St	3	1170	2.6	y*
Brazier St	Kimberley Ave and McLeod Ave	3	1260	2.4	y
Cuthbertson Ave	Shaftesbury Blvd and Southport Blvd	4	1110	3.6	y
Roch St	Kimberley Ave and McLeod Ave	4	1260	3.2	y
Betsworth Ave	Cullen Dr and Municipal Rd	5	980	5.1	y**
Louelda St	Kimberley Ave and McLeod Ave	5	1280	3.9	y*

*a portion of this segment is located within a school or playground area
**a portion of this segment contains a rural cross-section

3.3 VEHICULAR SPEED DATA

To compare vehicular speeds between study segments, speed data was collected between stop sign pairs at approximately midpoint. ITE (2000) states that data should be collected for at least a 24 hour period and that the location and length of study should be chosen based on the purpose of the study, resources available and common sense. As the purpose of this data collection is to compare vehicular speeds between study locations, speed data is collected where vehicular speeds are expected to be highest. Theoretically, speeds are maintained and most likely highest at midpoint because motorists will accelerate to a speed at which they feel comfortable, will continue travelling at that speed, and then will start to decelerate when approaching the stop sign. Figure 3.12 illustrates this characteristic for each stop sign density case. Each dot on the schematic represents a stop sign. For example, in the first schematic, there are two stop signs – one at the beginning of the segment and one at the end. In the second schematic, there are three stop signs on the one-kilometre segment. Theoretically, the maximum speed would be reached approximately at the midpoint of a segment between any given two stop signs. As previously discussed, the data collection tubes were laid out approximately at the midpoint between pairs of stop signs to capture vehicle speeds as they were travelling at the theoretical maximum speed.

Vehicular speed data was collected by the pneumatic road tube method 24 hours a day for seven continuous days to obtain a larger sample size and to provide day of week and time of day information. Traffic volume data was also collected at the same time. Two flexible road tubes were connected to an automatic recording device that records the directional speed of each vehicle passing over the tubes. The road tubes were placed across the roadway at a known distance apart. Figure 3.13 shows an example of a pneumatic road tube setup for measuring vehicular speeds. Figure 3.14 shows a close up of an automatic recording device.

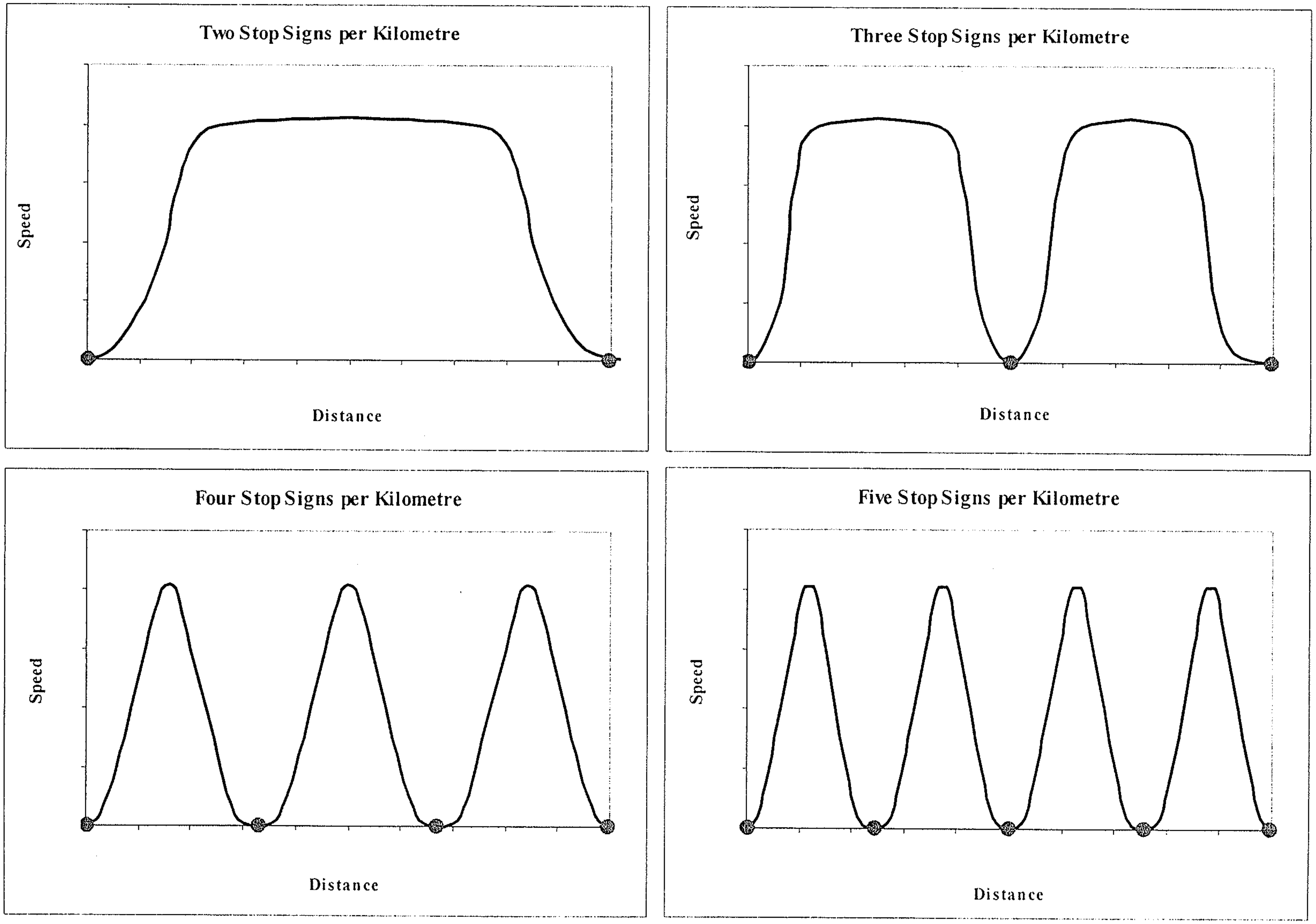

Figure 3.12: Theoretical Speed Profile Curves

Figure 3.13: Pneumatic Road Tube Setup

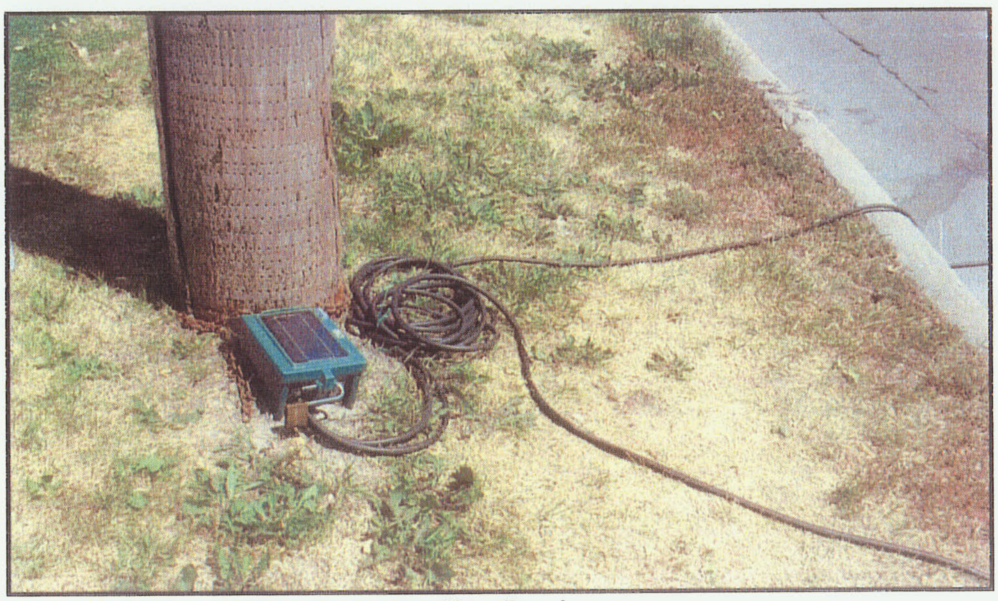

Figure 3.14: Automatic Recording Device

For this research, road tubes were placed approximately 2.4 metres (8 feet) apart. Vehicular speeds were calculated by dividing the distance between the road tubes by the time for a vehicle to travel between the road tubes. Speed data was recorded in 15 minute time intervals within different pre-programmed speed bins. Speed bins are as shown in

Table 3.4. Speeds that fall within the bin between 90 and 9999 typically represent equipment malfunctions due to machine movement or when two vehicles in opposite directions travel over the road tubes at the same time (City of Winnipeg, 2006).

Table 3.5 lists the block locations where the road tubes were placed, which is approximately midpoint between stop sign locations. Figures 3.15a and 3.15b show the road tube locations on each study segment.

Table 3.4: Speed Bins (km/h)
0-19
20-29
30-39
40-45
46-50
51-54
55-59
60-64
65-69
70-74
75-79
80-84
86-89
90-9999

Table 3.5: Road Tube Locations

Stop Sign Density	Street	Block (approximately midpoint)
2 stop signs per kilometre	Fleet Ave	Queenston St and Niagara St
	Gilmore Ave	Evenlea Walk (east leg) and Greenlea Cv (east leg)
3 stop signs per kilometre	Mathers Ave	Brock St and Queenston St Mathers Bay East and Mathers Bay East
	Brazier St	Hazeldell Ave and Linden Ave Dunbeath Ave and Colvin Ave
4 stop signs per kilometre	Cuthbertson Ave	Bower Blvd and Laidlaw Blvd Kelvin Blvd and Hosmer Blvd Lamont Blvd and Southport Blvd
	Roch St	Dunrobin Ave and Oakview Ave Greene Ave and Roberta Ave Dunbeath Ave and Colvin Ave
5 stop signs per kilometre	Betsworth Ave	Cullen Dr and Eager Cr Buckle Dr and Norlorne Dr (east leg) Charleswood Rd and Berkley St Berkley St and Municipal Rd
	Louelda St	Green Valley Bay and Green Valley Bay Tregar Bay and Antrim Rd Tomlinson Ave and Meighen Bay (south leg) Stacey Bay and Stacey Bay

Figure 3.15a: Road Tube Locations

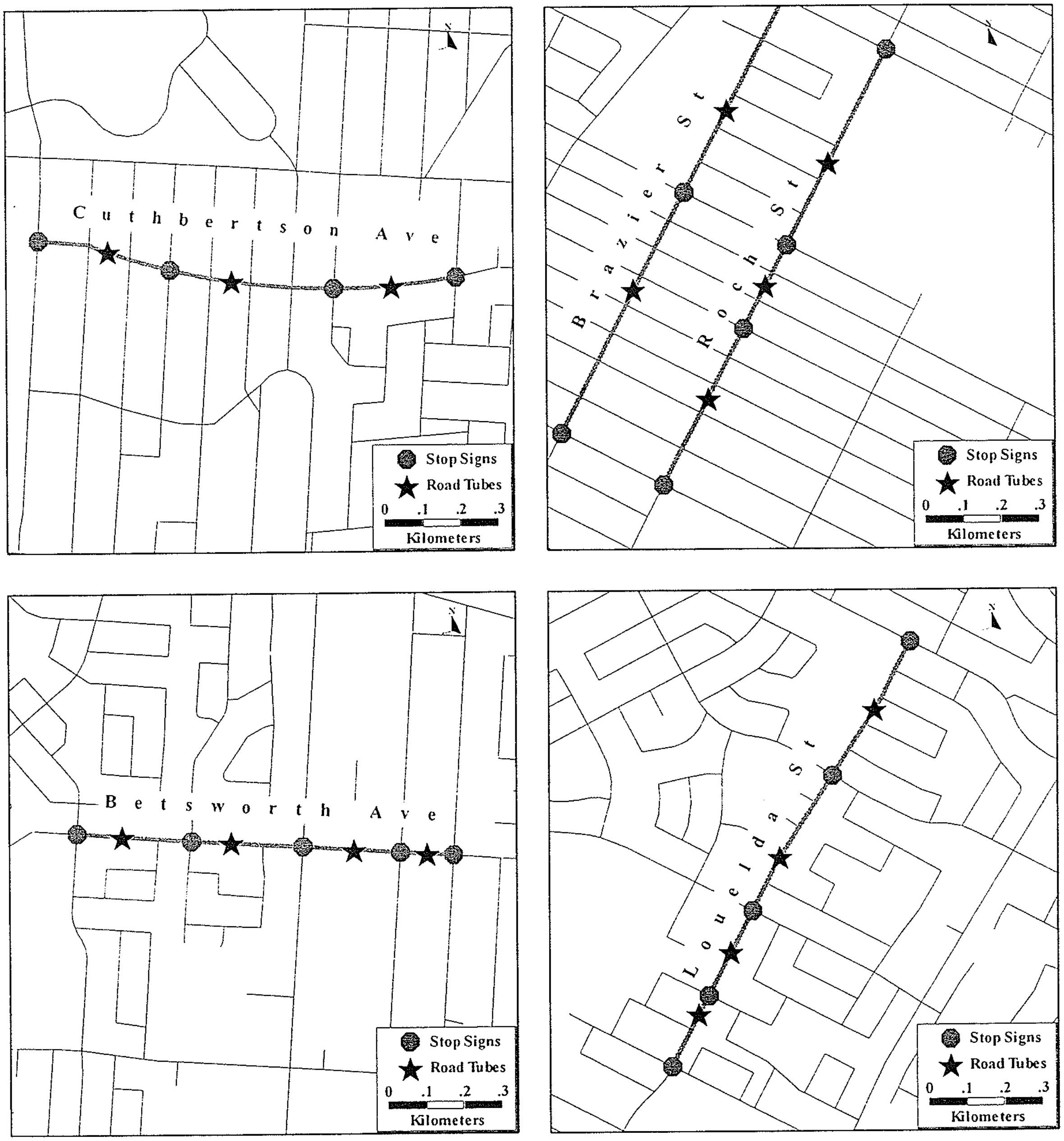

Figure 3.15b: Road Tube Locations

3.4 DRIVER COMPLIANCE WITH STOP SIGNS

To determine driver compliance with stop signs, field observations were undertaken at selected study intersections. There are a total of twenty-eight stops signs within the eight selected study segments. Field observations were completed at both end point intersections of each study segment in the direction of traffic leaving the study area for consistency purposes. The intersection leg within the study area was observed. The data from the end point intersections within each study segment was combined to provide results for the eight study segments. Table 3.6 lists the selected intersections to carry out the field observations.

Field observations were conducted during a typical weekday off-peak hour. This was done to minimize the possibility of drivers being required to stop at the stop sign due to an increase in cross street traffic. Observation studies were conducted on a Tuesday, Wednesday, or Thursday. They were not conducted on holidays, Mondays, or Fridays as these days may not be representative of typical weekday conditions (Rakha, 2004). ITE (2000) states that observation studies should be completed for at least 100 samples for as long as required.

Table 3.6: Intersection Locations to Observe Driver Compliance

Two stop signs per km
Fleet Ave at Lindsay St and Elm St
Gilmore Ave at Rothesay St and Raleigh St
Three stop signs per km
Mathers Ave at Lindsay St and Waverley St
Brazier St at Kimberly Ave and McLeod Ave
Four stop signs per km
Cuthbertson Ave at Shaftesbury Blvd and Southport Blvd
Roch St at Kimberly Ave and McLeod Ave
Five stop signs per km
Betsworth Ave at Cullen Dr and Municipal Rd
Louelda St at Kimberly Ave and McLeod Ave

During field observations, each vehicle approaching the intersection was observed at the proper location to stop for the stop sign. The observation addressed whether the driver of the vehicle came to a complete stop (voluntarily or required), rolled through, or slightly reduced/did not reduce speed at the stop sign, which is referred to as did not stop. A "required" stop means that the driver had to stop due to the presence of another vehicle at the intersection (coming from another direction). A "voluntary" stop means that the driver fully stopped even when there were no other vehicles present at the intersection.

The observer was situated such that the intersection leg being observed was unobstructed. Table 3.7 shows a sample worksheet for field observations. Driver compliance with stop signs was measured by the percent of drivers that were compliant and the percent of drivers that were not compliant at the study intersection. The results and analysis are discussed in Chapter 4.

Table 3.7: Sample Worksheet for Field Observations of Driver Compliance

Location ________________ Date ________________

Time ________ to ________ Weather ________________

Compliant		Non-Compliant	
Full Stop		Roll Through	Did Not Stop
Voluntary	Required		

Source: Designed by C. Desjardine, 2006

4.0 ANALYSIS OF SPEED DISTRIBUTIONS AND STOP SIGN COMPLIANCE

This chapter analyses the characteristics of speed distributions at each location selected for investigation. The chapter also presents the results of the analysis involving driver compliance with stop signs.

4.1 DATA COLLECTION

Speed data collection occurred during the months of October 2005, November 2005, and May 2006. Speed data was collected 24 hours per day for seven days at each location of interest. Data collected over seven days was trimmed to seven days to have a uniform set of data for all stop sign density cases.

Speed data was collected within the speed bins discussed in Chapter 3. Data within the speed bin of 90-9999 km/h was deleted for the analysis. The reason for this is that on residential streets when data falls within this range, it typically indicates an error and commonly occurs when setting up or taking down the machine, from someone shaking or kicking the machine, or when two vehicles in opposite directions travel over the road tubes at the same time (City of Winnipeg, 2006). This is common practice by the City of Winnipeg and it is done subsequent to visual screening of the data. A total of 282,106 observations were collected for this research at the selected locations combined. Details of these observations are discussed in section 4.2.

4.2 SPEED ANALYSIS OVERVIEW

Speed data for this research was collected at the point of potential maximum speeds. Theoretically, speeds are established and most likely highest at midpoint between stop sign pairs. This is because motorists accelerate to a speed at which they feel comfortable, and continue travelling at that speed, until it is time to begin decelerating when approaching the stop sign.

Speed data was collected for each study segment by direction of travel. Table 4.1 shows the seven day number of observations per direction of travel, study segment, and stop sign density case. The table also shows the weighted average weekday traffic for each study segment. This was calculated along each study segment based on Average Weekday Traffic and distance of each sub-segment. For example, a study segment with three stop signs has two sub-segments, each containing a different traffic volume. Assuming one sub-segment is 700 metres and the other sub-segment is 300 metres, the two traffic volume numbers were weighted based on the distances between the stop sign pairs. This provides one traffic volume to represent the study segment.

As speed data is typically collected in speed bins by the City of Winnipeg personnel and the output only shows how many vehicles are travelling within each speed bin, it is impossible to determine the actual speed of each vehicle at the time when they drove over the tubes. This is a reality of the speed data collection equipment and must be taken into account when analysing the data. For this research, it was assumed that all vehicles within the speed bin were travelling at the midpoint speed of each given speed bin. This

Table 4.1: Number of Observations in a 7 Day Period

Stop Sign Density	Number of Road Tubes	Total Observations	Study Segment	Total Observations by Direction	Total Observations by Road Segment	Average Weekday Traffic (AWDT)
Two stop signs per km	1	37562	Fleet Ave - EB	5295	11032	1900
			Fleet Ave - WB	5737		
			Gilmore Ave - EB	13013	26530	4000
			Gilmore Ave - WB	13517		
Three stop signs per km	2	76711	Mathers Ave - EB	7866	18886	1400
			Mathers Ave - WB	11020		
			Brazier St - NB	23937	57825	4300
			Brazier St - SB	33888		
Four stop signs per km	3	76799	Cuthbertson Ave - EB	3309	8023	500
			Cuthbertson Ave - WB	4714		
			Roch St - NB	33705	68776	3700
			Roch St - SB	35071		
Five stop signs per km	4	91034	Betsworth Ave - EB	13228	27263	1200
			Betsworth Ave - WB	14035		
			Louelda St - NB	34409	63771	2500
			Louelda St - SB	29362		
Total		282106				

assumption was made from a pragmatic perspective, as it is understood that there may be some vehicles travelling at speeds closer to the lower bound of the bin, and vehicles travelling closer to the upper bound of the bin. Table 4.2 shows the midpoint speed of each speed bin.

Table 4.2: Midpoint Speed of Each Speed Bin

Speed Bins, km/h	Midpoint Speed, km/h
0-19	9.5
20-29	24.5
30-39	34.5
40-45	42.5
46-50	48
51-54	52.5
55-59	57
60-64	62
65-69	67
70-74	72
75-79	77
80-84	82
85-89	87

The bins illustrated in Table 4.2 are pre-programmed in the equipment. All speed analyses done in Winnipeg make use of the same types of bins. As the table shows, after 40 km/h, the speed bins are divided into four to six kilometre per hour intervals. This results in midpoint values which are closer to the true speeds of individual vehicles, as the range of possible values has significantly been reduced.

4.3 PRELIMINARY ANALYSIS

The first aspect of the engineering analysis for this research was to identify similarities or differences regarding directional speed distributions for each study segment. There were eight study segments to consider, as illustrated in Table 4.1. Each of these segments fell under different stop sign density classifications as previously discussed.

A statistical analysis of variance (ANOVA) was used to determine if the directional speed data of each study segment was statistically different. In other words, the analysis was done to determine if the eastbound speed distribution for a given segment was different from that in the westbound direction (the same was done for northbound and southbound directions where applicable). From a statistical perspective, if the directional speed data was not statistically different, then the speed data was considered the same for both directions and could be combined. If the directional speed data was statistically different, then the speed data was considered different and from a statistical perspective, could not be combined.

The initial statistical analysis was conducted using the One-way ANOVA as the statistical test. This test is commonly used instead of the T-test to compare the means of three or more treatments. In this context, a treatment is any pair of values being compared to each other for statistical difference. Table 4.3 shows the treatments analyzed in this research.

The one-way ANOVA test assumes a normal distribution and equal variance in the data. When the distribution is not normal and the variance is not equal, the Kruskal-Wallis one-way ANOVA on Ranks test is used instead. The difference between the two tests is that the one-way ANOVA test compares the means of the treatments, whereas the Kruskal-Wallis one-way ANOVA on Ranks test compares the medians of the treatments.

Table 4.3: Treatments Analysed

Fleet Ave EB vs. Fleet Ave WB Gilmore Ave EB vs. Gilmore Ave WB Fleet Ave vs. Gilmore Ave
Mathers Ave EB vs. Mathers Ave WB Brazier St NB vs. Brazier St SB Mathers Ave vs. Brazier St
Cuthbertson Ave EB vs. Cuthbertson Ave WB Roch St NB vs. Roch St SB Cuthbertson Ave vs. Roch St
Betsworth Ave EB vs. Betsworth Ave WB Louelda St NB vs. Louelda St SB Betsworth Ave vs. Louelda St

EB-eastbound; WB-westbound; NB-northbound; SB-southbound

The initial statistical analysis found that none of the treatments had a normal distribution or equal variances. This could be due to different sizes of bins used in the data collection process. The Kruskal-Wallis one-way ANOVA on Ranks test was then used to analyze the treatments. Table 4.4 summarizes the results of the statistical analysis for significant differences regarding directional speeds. Table 4.5 illustrates the mean and median speeds of each study segment by direction based on the analysis.

Table 4.4: Summary of the Directional Statistical Analysis
Kruskal-Wallis One-Way Analysis of Variance on Ranks

Treatment	**Significantly Different**	**Difference of Means (km/h)**
Fleet Ave EB vs. Fleet Ave WB	yes	1.4
Gilmore Ave EB vs. Gilmore Ave WB	no	0.1
Mathers Ave EB vs. Mathers Ave WB	no	0.3
Brazier St NB vs. Brazier St SB	yes	1.2
Cuthbertson Ave EB vs. Cuthbertson Ave WB	yes	1.4
Roch St NB vs. Roch St SB	yes	0.7
Betsworth Ave EB vs. Betsworth Ave WB	no	0.1
Louelda St NB vs. Louelda St SB	yes	1.6

Table 4.5: Mean and Median Speeds of Study Segment by Direction of Travel

	Mean Speed			**Median Speed**		
	Direction 1	**Direction 2**	**Combined**	**Direction 1**	**Direction 2**	**Combined**
2 stop signs/km						
Fleet Ave	42.1	40.7	41.4	42.5	42.5	42.5
Gilmore Ave	49.6	49.4	49.6	52.5	52.5	52.5
3 stop signs/km						
Mathers Ave	42.6	42.3	42.4	42.5	42.5	42.5
Brazier St	42.9	41.7	42.2	42.5	42.5	42.5
4 stop signs/km						
Cuthbertson Ave	42.4	43.8	43.2	42.5	42.5	42.5
Roch St	46.6	45.9	46.2	48.0	48.0	48.0
5 stop signs/km						
Betsworth Ave	42.2	42.2	42.2	42.5	42.5	42.5
Louelda St	45.1	43.5	44.4	48.0	42.5	42.5

Note: Direction 1 refers to EB for avenues and NB for streets; Direction 2 refers to WB for avenues and SB for streets

Table 4.4 shows that from a statistical perspective, the directional speed distributions of only three study segments can be combined (i.e., Gilmore Avenue, Mathers Avenue, and Betsworth Avenue). However, from a practical perspective, based on engineering judgment and professional experience with roadway design and traffic operations, this research determined that the directional distributions for all study segments can be combined. This was based on the observation of differences in mean speeds as shown in Tables 4.4 and 4.5. The largest directional difference in mean speed was 1.6 km/h for Louelda Street northbound versus southbound. The road tube equipment manufacturer (Jamar, 2006) indicated that the equipment could be expected to have a 5 % error when the road tubes are in good condition and the equipment is set up properly. At a speed of 50 km/h, an error of +/- 2.5 km/h can be expected as best case. Therefore, it is practical to combine directional speed data with a difference in mean speeds of 1.6 km/h.

The next step in the engineering analysis was to determine if speed data from study segments in each stop sign density case could be combined. For example, could the bi-directional speed data for Fleet Avenue be combined with the bi-directional speed data for Gilmore Avenue (these are the two study segments that represent a stop sign density of two stop signs per kilometre). Table 4.6 shows the results of the analysis.

Table 4.6: Summary of the Study Segment Statistical Analysis
Kruskal-Wallis One-Way Analysis of Variance on Ranks

Treatment	**Significantly Different**	**Difference of Means**
Fleet Ave vs. Gilmore Ave	yes	8.3
Mathers Ave vs. Brazier St	no	0.3
Cuthbertson Ave vs. Roch St	yes	3.0
Betsworth Ave vs. Louelda St	yes	2.2

Tables 4.5 and 4.6 determined from a statistical perspective, road segments containing three stop signs per kilometre could be combined (i.e. Mathers Avenue and Brazier Street). From the tables, it was also determined that it is practical to combine road segments containing four and five stop signs per kilometre. The largest difference in mean for the study segments was 3.0 km/h for Cuthbetson Avenue versus Roch Street. As the road tubes can have at least a 5 % error, it is practical to combine road segments with a difference of means of about 3.0 km/h. The mean speed difference between Fleet Avenue and Gilmore Avenue was too large (8 km/h) to allow for the amalgamation of these two segments into one case for analysis. Therefore, this research uses the following cases for the analysis of speed distribution as a function of stop sign density:

- Fleet Avenue
- Gilmore Avenue
- Three stop signs per kilometre (combines Mathers Avenue and Brazier Street)
- Four stop signs per kilometre (combines Cuthbertson Avenue and Roch Street)
- Five stop signs per kilometre (combines Betsworth Avenue and Louelda Street)

4.4 STOP SIGN DENSITY AND VEHICULAR SPEED

This analysis is conducted using the combined speed data as discussed in the previous section. In addition to combining the directional speed data for each study segment, the analysis also combines street segments falling under the following stop sign densities: three, four, and five stop signs per kilometre. Figures 4.1 to 4.5 illustrate the cumulative speed distribution developed for each of these cases (the Appendix shows speed distribution curves and cumulative speed distributions developed for the preliminary analysis). Table 4.7 summarizes the mean, 50th percentile, and 85th percentile speeds as measured from the cumulative speed distribution curves for the analysed data.

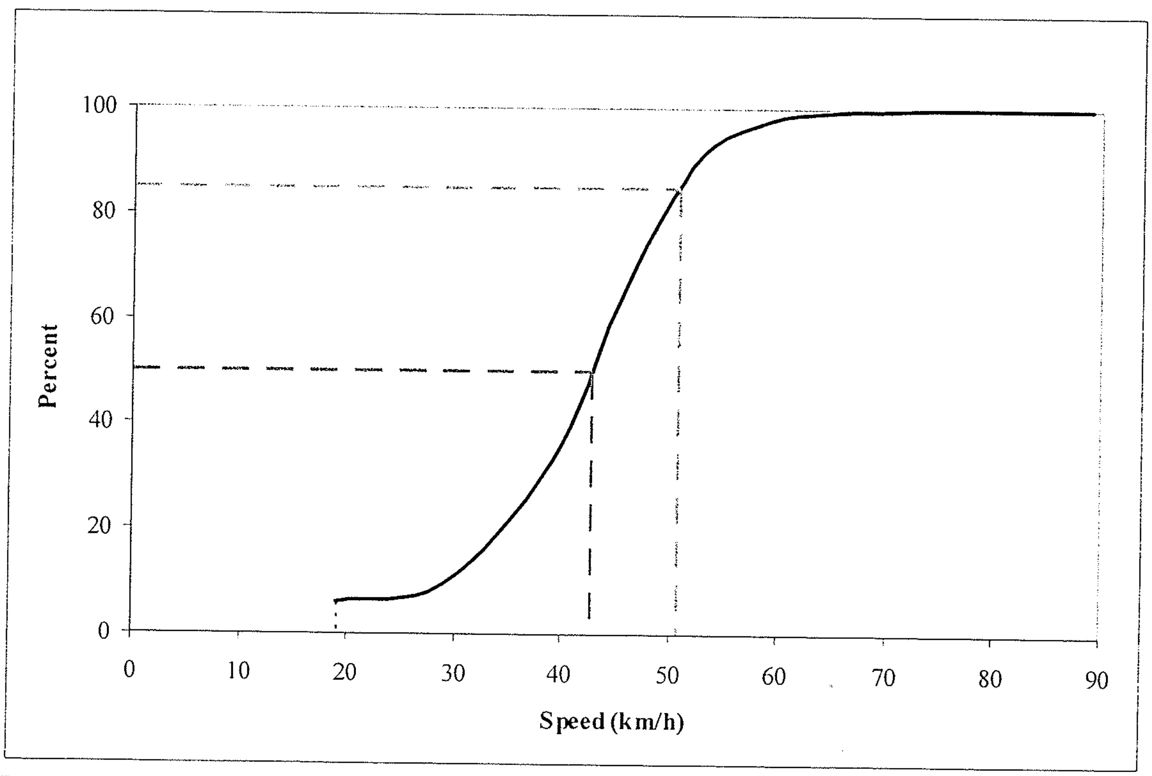

Figure 4.1: Cumulative Speed Distribution for Fleet Avenue

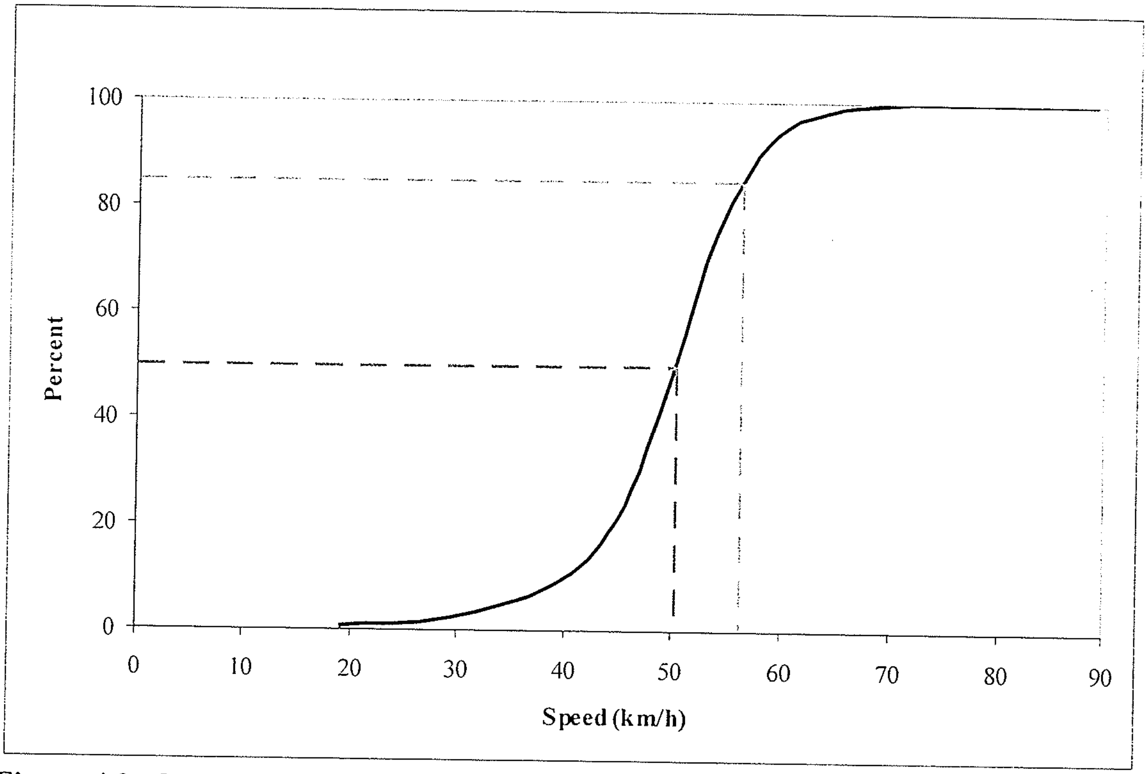

Figure 4.2: Cumulative Speed Distribution for Gilmore Avenue

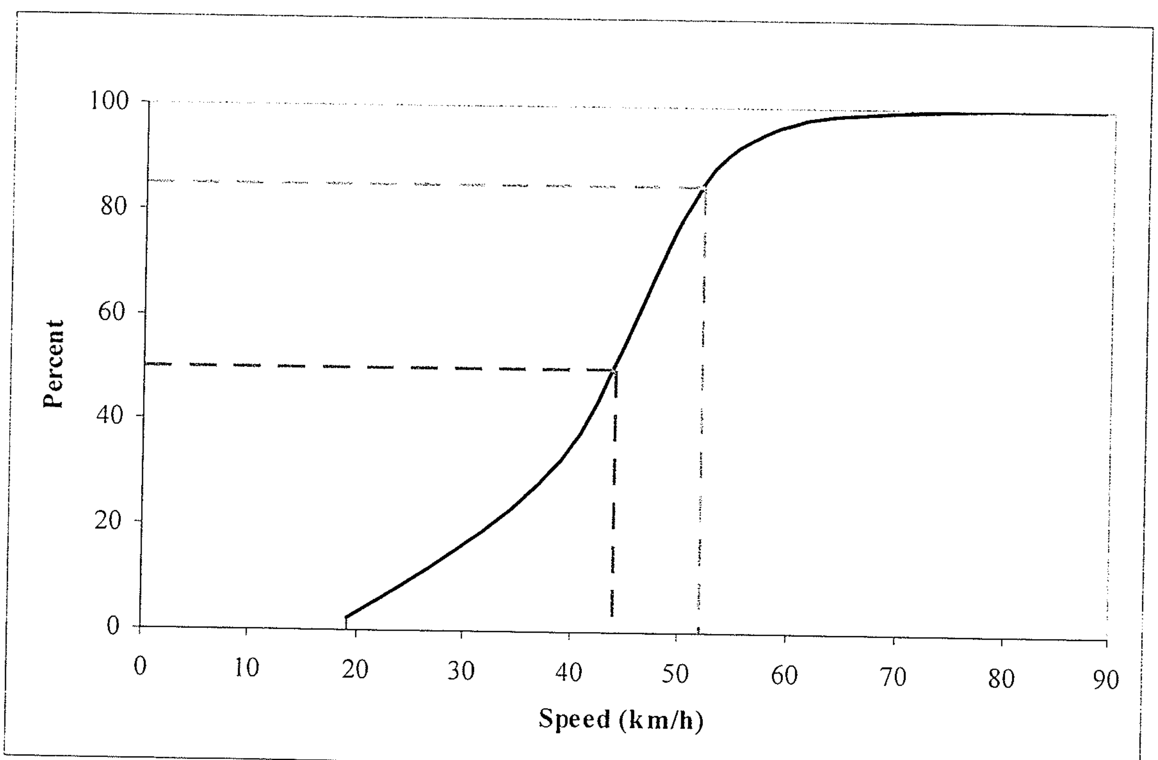

Figure 4.3: Cumulative Speed Distribution for Three Stop Signs per Kilometre

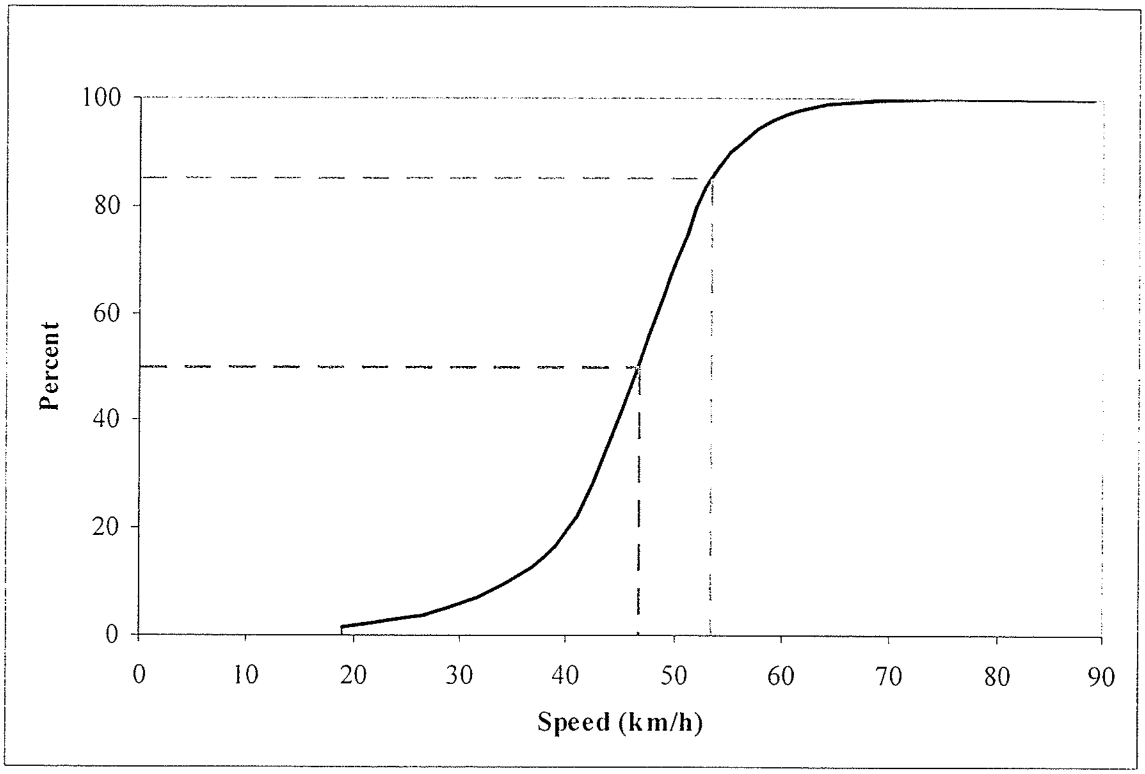

Figure 4.4: Cumulative Speed Distribution for Four Stop Signs per Kilometre

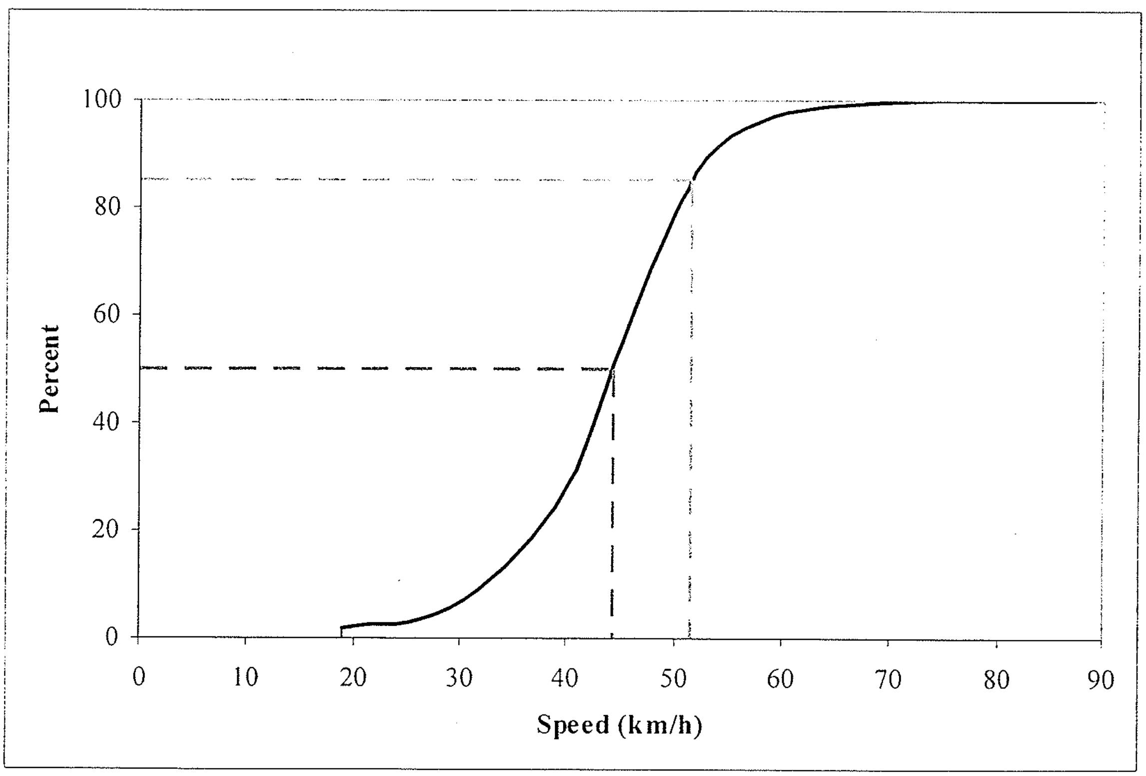

Figure 4.5: Cumulative Speed Distribution for Five Stop Signs per Kilometre

Table 4.7: Summary of Vehicular Speeds

Stop Sign Density	Mean Speed (km/h)	50^{th} Percentile Speed (km/h)	85^{th} Percentile Speed (km/h)
Fleet Ave	41.4	42.8	50.8
Gilmore Ave	49.6	50.4	56.3
3 stop signs/km	42.2	44.0	52.0
4 stop signs/km	45.9	46.7	53.4
5 stop signs/km	43.7	44.2	51.6

Table 4.7 shows that Gilmore Avenue contains the highest mean, 50^{th} percentile, and 85^{th} percentile speeds, followed by street segments that have four stop signs per kilometre. The table also shows the 85^{th} percentile speeds range between 50.8 km/h and 56.3 km/h. Posted speed limits are typically based on the 85^{th} percentile vehicular speed (City of Winnipeg, 2006). The posted speed limit in each stop sign density case is 50 km/h. From Figures 4.1 to 4.5, it can be seen that Gilmore Avenue has the highest percent of vehicles travelling over 50 km/h. Approximately one half of the vehicles operating on that road segment are travelling at or above the speed limit when they reach the midpoint of the segment. Fleet Avenue has the lowest percent of vehicles (17 %) travelling greater than 50 km/h.

Tables 4.8 and 4.9, and Figures 4.6 and 4.7 show the mean and 85^{th} percentile speeds by day of week for each stop sign density case. From Tables 4.8 and 4.9 and Figures 4.6 and 4.7 it can be seen that on Gilmore Avenue vehicular speeds are larger than at the other locations by day of week. Road segments with four stop signs per kilometre show the second highest mean speed and 85^{th} percentile speed on any given day of the week. Fleet

Avenue, which similar to Gilmore Avenue falls under the two stop signs per kilometre category for this analysis, shows the lowest vehicular speeds. This raises the issue of why the marked difference between the two streets (Gilmore Avenue and Fleet Avenue) if they both meet the criteria for this research. In addition to these observations, the figures show that street segments with five stop signs per kilometre exhibit a slightly different behaviour than the other cases being considered. The mean speed, as well as the 85^{th} percentile speed is higher from Thursday to Sunday than for the other days of the week. The highest speeds are found to take place during weekends. The opposite is observed for segments with three stop signs per kilometre where weekends record the lowest mean and 85^{th} percentile speeds. From an engineering perspective, these differences are practically negligible.

Overall, the results of Tables 4.8 and 4.9 and Figures 4.6 and 4.7 show that day of week does not affect the vehicular speeds, except for slight variations as discussed above.

Tables 4.10 and 4.11, and Figures 4.8 and 4.9 show the mean and 85^{th} percentile speeds during the AM peak period, PM peak period, and off peak period. The AM peak and PM peak period are defined as two consecutive hours with the highest volume of traffic. The AM peak and PM peak period were determined for each stop sign density case.

Table 4.8: Mean Speeds by Day of Week (km/h)

Stop Sign Density	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Fleet Ave	41.3	40.9	42.2	41.8	42.4	40.3	41.2
Gilmore Ave	49.6	49.6	49.4	50.0	49.6	49.6	49.7
3 stop signs/km	42.1	41.8	43.0	42.7	42.4	41.6	41.8
4 stop signs/km	46.1	45.7	45.9	46.4	46.0	45.1	46.0
5 stop signs/km	43.3	43.3	42.9	43.9	44.3	44.3	44.7

Table 4.9: 85th Percentile Speeds by Day of Week (km/h)

Stop Sign Density	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Fleet Ave	51.0	50.2	51.4	50.3	51.4	50.3	50.8
Gilmore Ave	56.3	56.0	56.3	56.8	56.4	56.3	56.3
3 stop signs/km	51.5	52.5	52.7	52.6	51.8	50.9	51.1
4 stop signs/km	53.5	53.3	53.5	54.0	53.4	52.9	53.8
5 stop signs/km	51.5	50.9	50.8	51.9	52.4	52.0	52.5

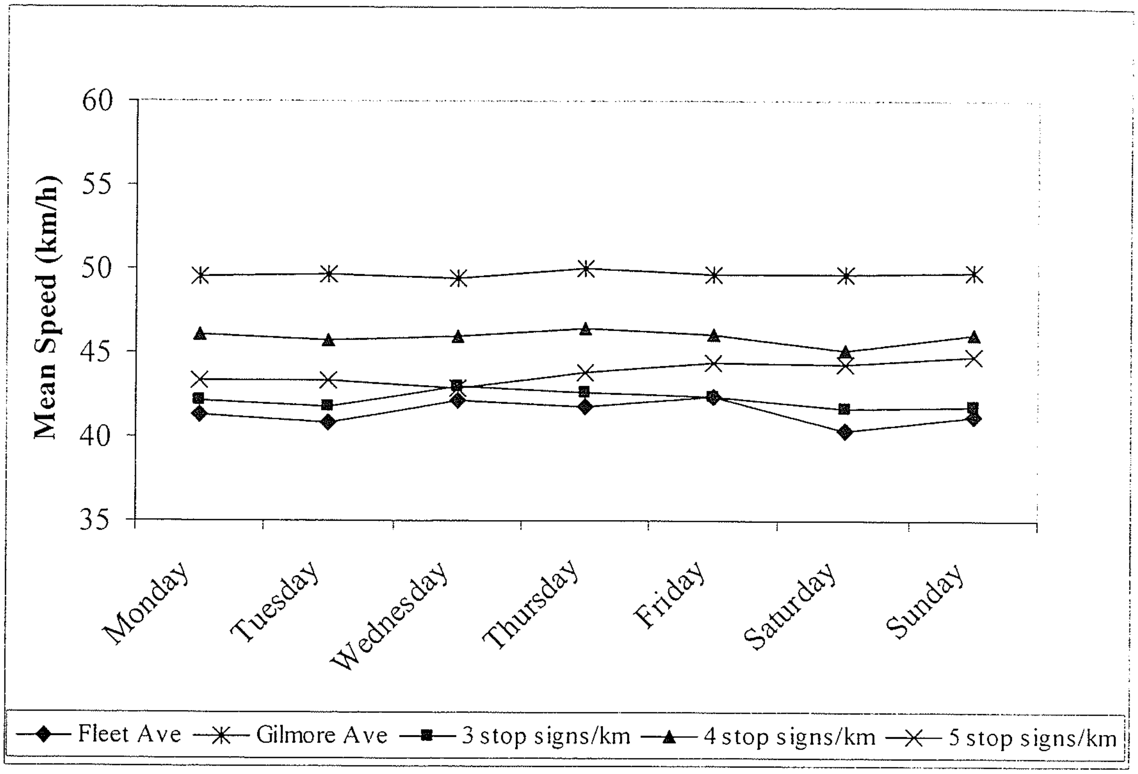

Figure 4.6: Mean Speeds by Day of Week

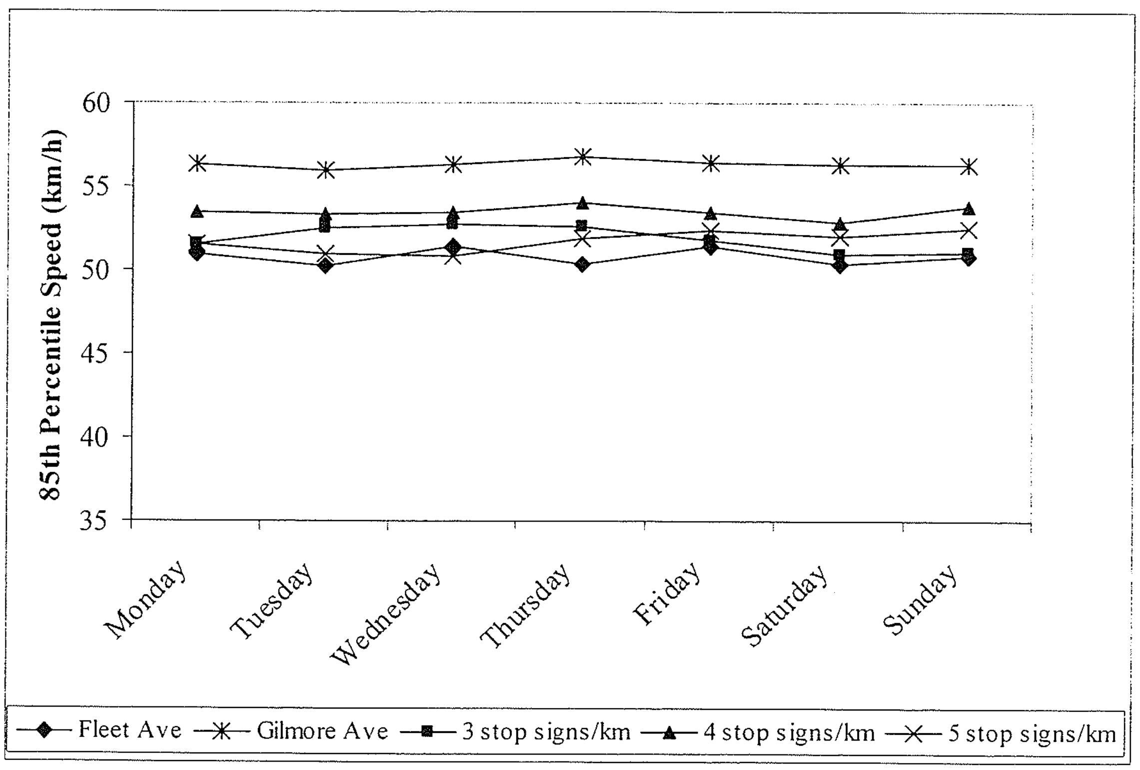

Figure 4.7: 85th Percentile Speeds by Day of Week

Table 4.10: Mean Speeds by Time of Day (km/h)

Stop Sign Density	AM Peak	PM Peak	Off Peak
Fleet Ave	40.9	41.7	41.4
Gilmore Ave	49.4	50.5	49.5
3 stop signs/km	43.1	41.8	42.2
4 stop signs/km	45.9	46.3	45.1
5 stop signs/km	42.9	43.2	44.0

Table 4.11: 85th Percentile Speeds by Time of Day (km/h)

Stop Sign Density	AM Peak	PM Peak	Off Peak
Fleet Ave	50.6	50.6	50.9
Gilmore Ave	56.4	56.7	56.2
3 stop signs/km	52.2	51.7	51.8
4 stop signs/km	53.1	53.8	52.9
5 stop signs/km	51.1	51.2	51.8

From these Tables and Figures, it can be seen that Gilmore Avenue contains the highest vehicular speeds during the time periods analysed. Road segments with four stop signs per kilometre show the second highest mean speed and 85th percentile speed during the time periods analysed. Fleet Avenue shows the lowest vehicular speeds by time of day. Overall, similar to the day of week situation, time of day does not affect vehicular speeds, except for slight variations as shown in the figures.

In addition to the previous analysis, this research also investigated the extent to which vehicular traffic exceeds the posted speed limit on the given road segments. Table 4.12 and Figure 4.10 show the percentage of vehicles travelling greater than 50 km/h by day of week for each stop sign density case.

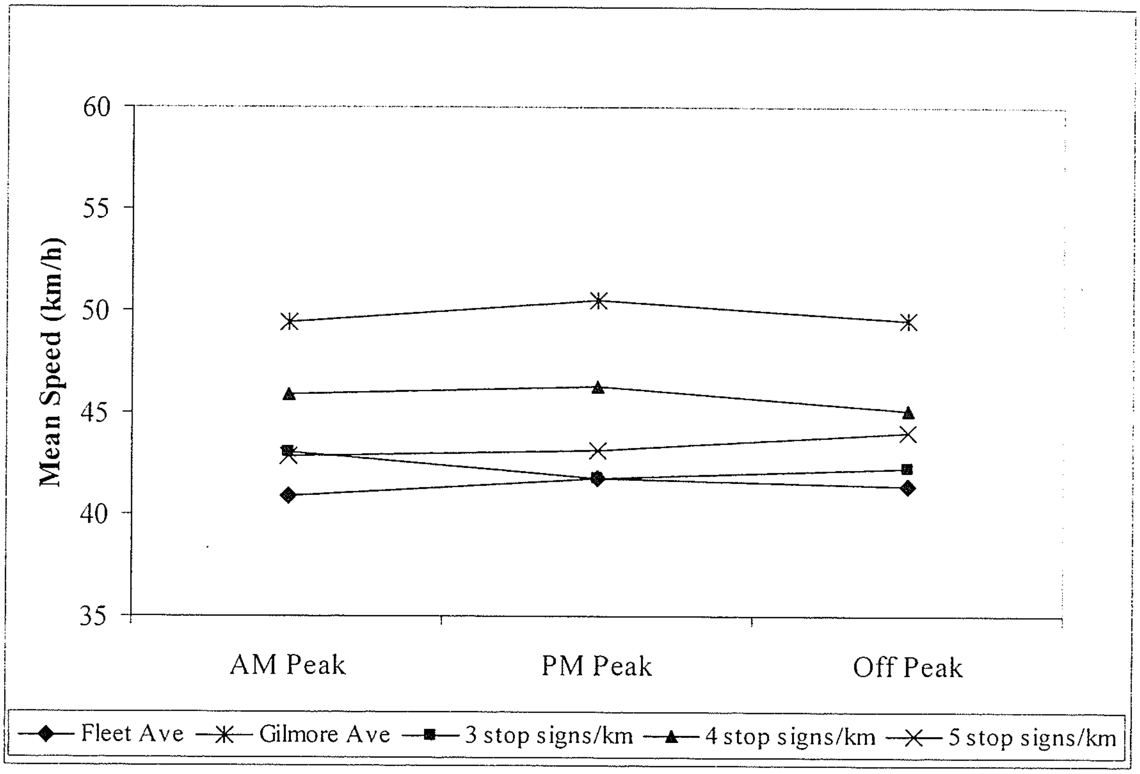

Figure 4.8: Mean Speeds by Time of Day

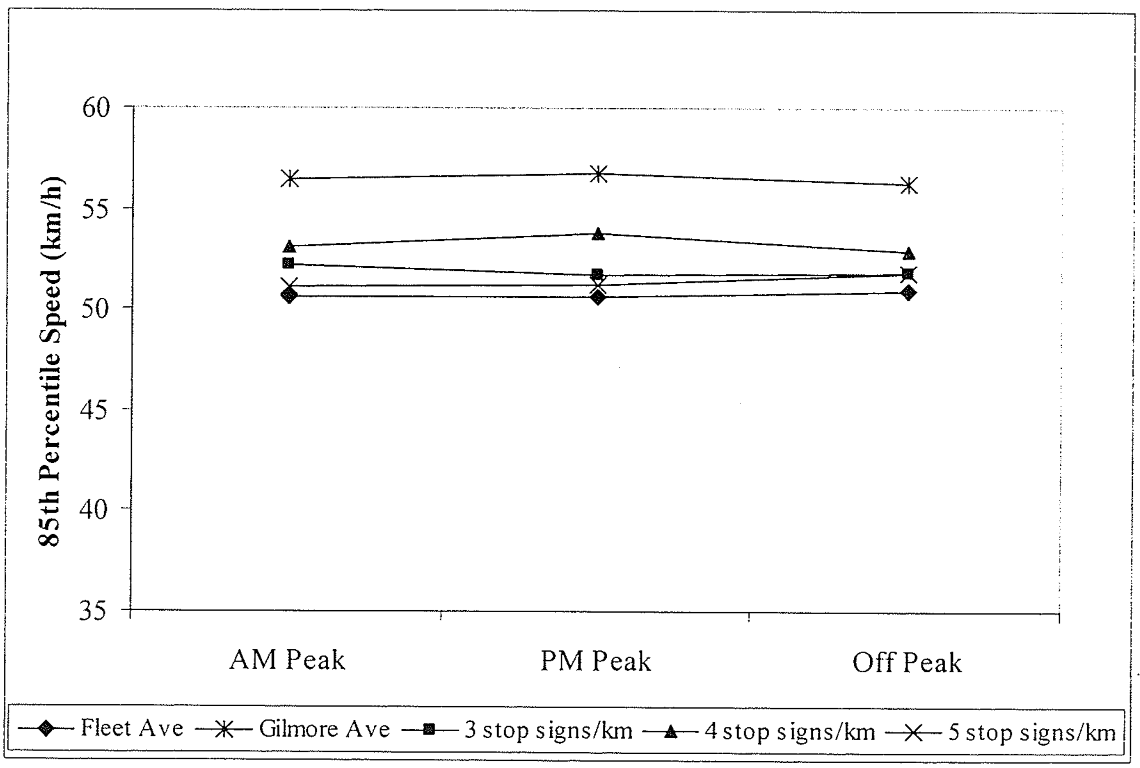

Figure 4.9: 85th Percentile Speeds by Time of Day

Table 4.12: Percent of Vehicles Travelling Greater than 50 km/h by Day of Week

Stop Sign Density	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Fleet Ave	18	15	20	16	19	16	17
Gilmore Ave	51	52	51	54	51	51	51
3 stop signs/km	20	22	24	24	22	18	19
4 stop signs/km	32	29	31	33	30	28	31
5 stop signs/km	20	18	17	22	24	22	25

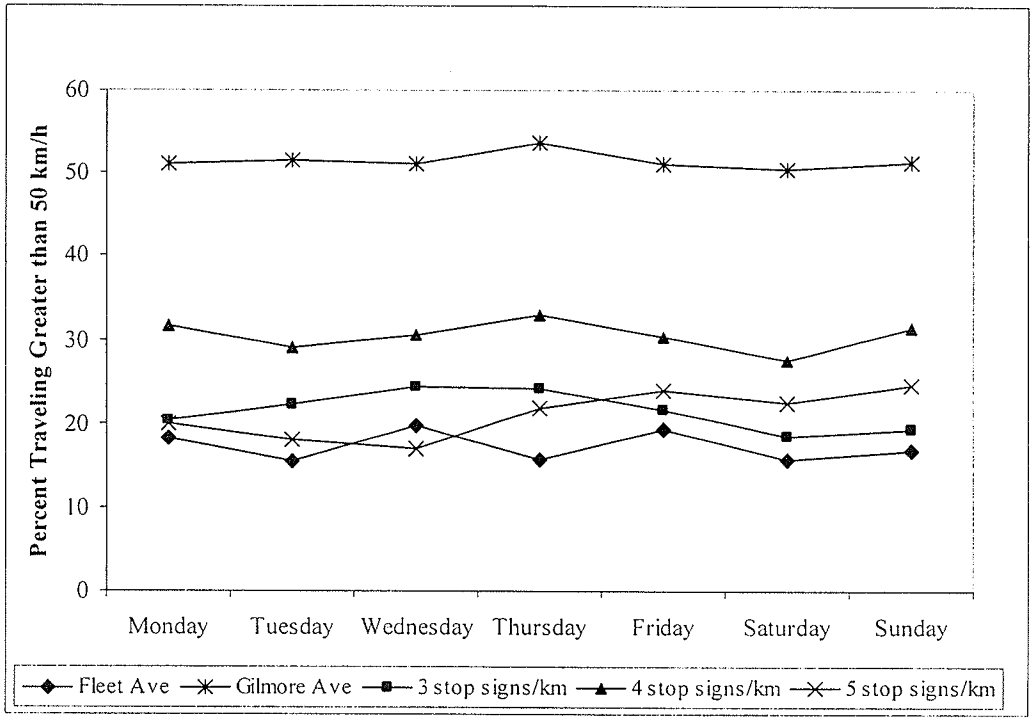

Figure 4.10: Percent of Vehicles Travelling Greater than 50 km/h by Day of Week

From Table 4.12 and Figure 4.10, it can be seen that Gilmore Avenue contains the highest percent of vehicles travelling greater than the speed limit of 50 km/h. About one-half of the vehicles travelling on Gilmore Avenue exceed the speed limit on any given day of the week, with Thursday being the highest at 54 %. Road segments with four stop signs per kilometre show the second worst case in terms of percentage of vehicles that exceed the speed limit on any given day of the week. About one-third of the vehicles travelling on these road segments do so over the speed limit. Fleet Avenue shows the smallest percentage of violations involving vehicular speed. In addition, it can be seen that road segments with five or three stop signs per kilometre show a different behaviour than that observed for the other categories. Depending on the day of week, the percentage of vehicles exceeding the speed limit may range from 17 % to 25 % (for five stop signs per kilometre), and from 18 % to 24 % (for three stop signs per kilometre). Segments with three stop signs per kilometre exhibit a lower number of speed violations during weekends, which is contrary to the situation observed for segments with five stop signs per kilometre.

Table 4.13 shows the percent of vehicles travelling greater than 50 km/h during the AM peak period, PM peak period, and off peak period. Figure 4.11 shows the percent of vehicles travelling greater than 50 km/h by time of day. From Table 4.13 and Figure 4.11, Gilmore Avenue contains the highest percent of vehicles travelling greater than 50 km/h for each analysed time period, followed by road segments with four stop signs per kilometre. Fleet Avenue contains the lowest number of vehicles travelling greater than 50 km/h. Figure 4.11 also shows that about 55 % of vehicles travelling on Gilmore

Avenue do so at speeds greater that 50 km/h during the PM peak period, compared to about 50 % during the other two time periods. Other road segments do not exhibit any change in terms of vehicles travelling greater than the speed limit as a function of time of day.

Table 4.13: Percent of Vehicles Travelling Greater than 50 km/h by Time of Day

Stop Sign Density	**AM Peak**	**PM Peak**	**Off Peak**
Fleet Ave	16	17	17
Gilmore Ave	50	56	51
3 stop signs/km	23	21	22
4 stop signs/km	29	32	30
5 stop signs/km	19	19	22

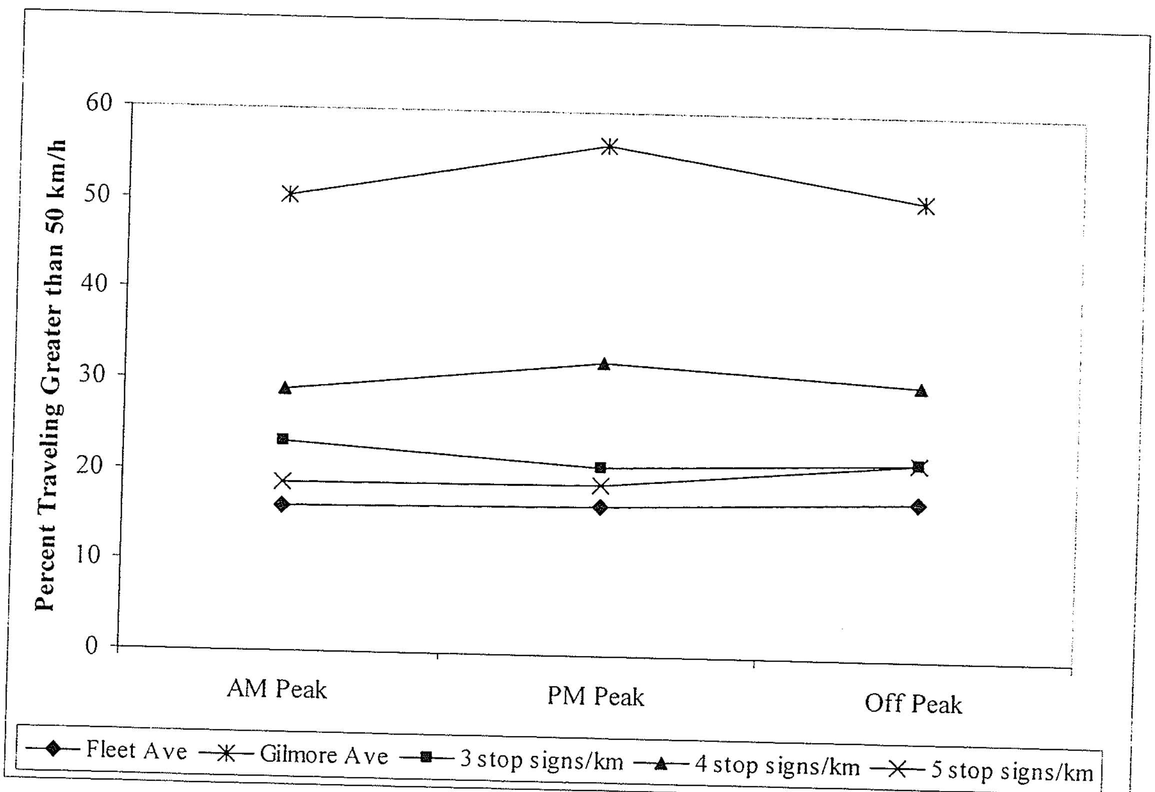

Figure 4.11: Percent of Vehicles Travelling Greater than 50 km/h by Time of Day

4.5 DRIVER COMPLIANCE WITH STOP SIGNS

An analysis of driver compliance with stop signs was also conducted in this research to complement the speed data. Field observations were conducted in April 2006 and May 2006. The field observations were completed during a typical weekday off-peak hour between 09:45 and 12:00. All observations studies were conducted for at least 100 vehicles for each study segment as recommended by ITE (2000). The field observation study collected 786 minutes of data and 728 observations of driver compliance with stop signs for this research.

Field observations were conducted by the observer watching each vehicle stop at the stop sign. The observer indicated whether each vehicle made a complete stop (voluntary or required), rolled through the stop sign, or did not stop at the stop sign. Driver compliance was divided into two categories: voluntary and required. A "Voluntary" stop means that the driver fully stopped even when there were no other vehicles present at the intersection. A "Required" stop means that the driver had to stop due to the presence of another vehicle at the intersection (coming from another direction). The observations also included the percent of drivers that rolled through the stop sign and the percent of drivers that did not stop at the intersection.

Field observations were completed at the end point intersections of each study segment in the direction of traffic leaving the study area. The intersection leg within the study area was observed. Table 4.14 lists the intersections where driver compliance was observed.

Table 4.14: Intersection Locations to Observe Driver Compliance

2 stop signs/km
Fleet Ave at Lindsay St and Elm St
Gilmore Ave at Rothesay St and Raleigh St
3 stop signs/km
Mathers Ave at Lindsay St and Waverley St
Brazier St at Kimberly Ave and McLeod Ave
4 stop signs/km
Cuthbertson Ave at Shaftesbury Blvd and Southport Blvd
Roch St at Kimberly Ave and McLeod Ave
5 stop signs/km
Betsworth Ave at Cullen Dr and Municipal Rd
Louelda St at Kimberly Ave and McLeod Ave

Observation data is analysed for the eight study segments. Table 4.15 and Figure 4.12 show a summary of field observations of driver compliance at stop signs for each of the eight study segments. There are a large number of violations of stop signs, regardless of the road segment. For example, the largest number of violations occurred on Fleet Avenue, where over 80 percent of drivers rolled through the stop sign. This is a location which only has two stop signs per kilometre and it is also the study segment which showed the lowest speeds from the speed analysis. Roch Street shows the largest proportion of vehicles arriving at a complete stop (37 %) before proceeding through the intersection (this is a road segment with four stop signs per kilometre). Over 90 % of the complete stops were classified as required due to the presence of another vehicle at the intersection. The largest number of no-stopping violations was recorded on Mathers Avenue, where 18 % of vehicles did not stop at either of the intersections studied.

During the field visits, it was apparent that drivers were treating the stop sign on Mathers Avenue at Waverley Street as a yield sign and were not coming to a complete stop.

Table 4.15: Summary of Field Observations of Driver Compliance with Stop Signs

Study Segment	No. of Vehicles Observed	Driver Compliance			Driver Non-Compliance		
		Full Stop			Roll Through	Did Not Stop	Total
		Voluntary	Required	Total			
2 stop signs/km							
Fleet Ave	101	13	5	18	83	0	83
Gilmore Ave	100	6	16	22	65	13	78
3 stop signs/km							
Mathers Ave	88	5	15	20	52	16	68
Brazier St	122	6	35	41	67	14	81
4 stop signs/km							
Cuthbertson Ave	50	2	11	13	35	2	37
Roch St	96	3	33	36	49	11	60
5 stop signs/km							
Betsworth Ave	52	11	2	13	37	2	39
Louelda St	109	12	22	34	61	14	75
Total	728						

When combining all observations, it was found that about one-quarter of drivers comply with stop signs at intersections, and the remaining three-quarters do not comply either because they roll through the intersection or because they do not stop at all (about 6:1). This is consistent with findings in the literature. Furthermore, when drivers are not required to stop because there is no other vehicle present at the intersection, only about 10 % comply with stop signs.

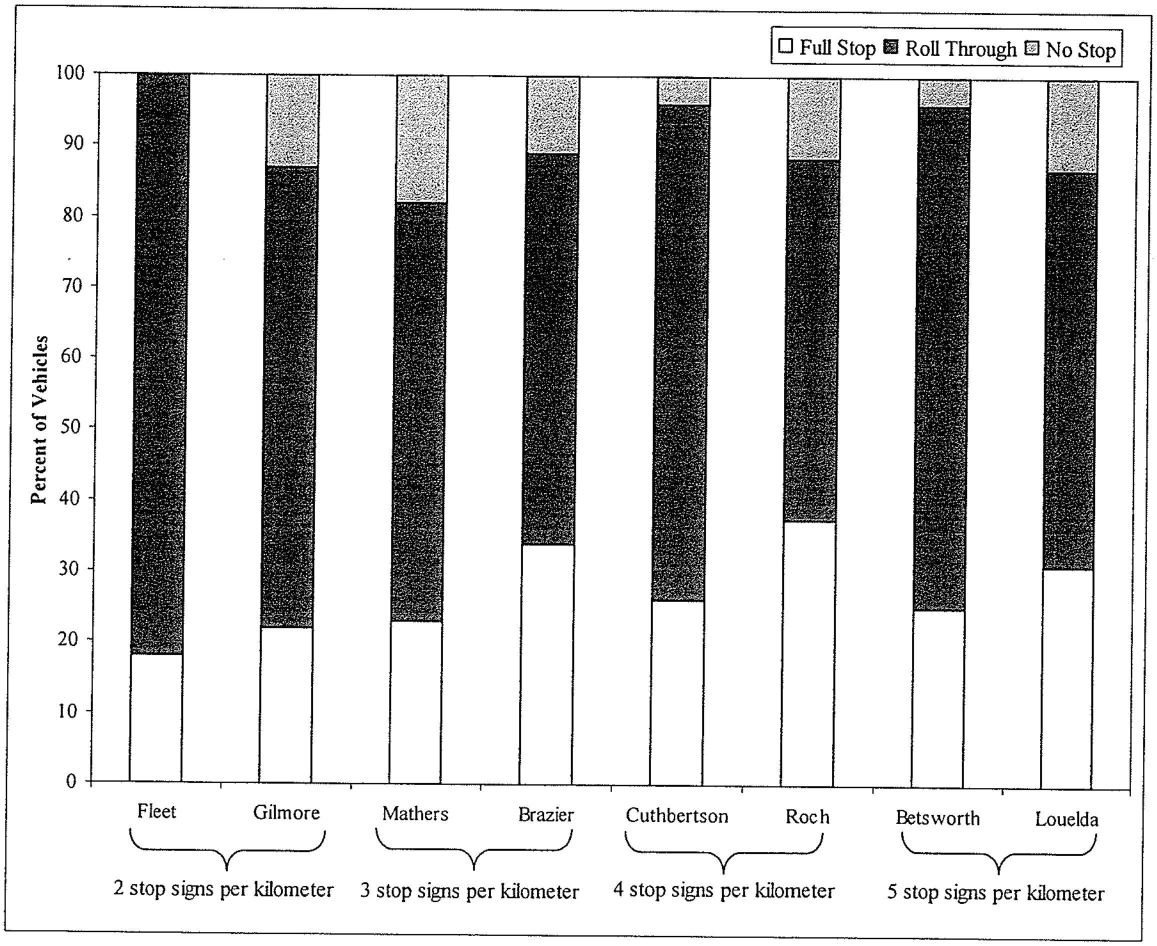

Figure 4.12: Driver Compliance with Stop Signs

4.6 SUMMARY OF ANALYSIS

This section summarizes the analysis of vehicular speed characteristics at midpoint between stop signs for each of the cases being considered in this research and the analysis of characteristics of driver compliance with stop signs for each study segment. Based on the preliminary statistical analysis, it was found that it was practical to combine the directional speed data for each road segment under consideration. This resulted in eight road segments with one speed distribution each. The speed distribution was that resulting from combining each of the directions of travel.

Subsequent analysis, combined with engineering judgment, revealed that it was practical to combine the vehicular speed data for most pairs of road segments falling under each of the stop sign density cases, except for the case dealing with two stop signs per kilometre. This resulted in the following cases used for further analysis:

- Fleet Avenue
- Gilmore Avenue
- Three stop signs per kilometre (which combined the bi-directional speeds of Mathers Avenue and Brazier Street)
- Four stop signs per kilometre (which combined the bi-directional speeds of Cuthbertson Avenue and Roch Street)
- Five stop signs per kilometre (which combined the bi-directional speeds of Betsworth Avenue and Louelda Street)

Further analysis revealed that there are significant differences in vehicular speeds observed on Gilmore Avenue from those observed on Fleet Avenue. This is particularly important given that both of these road segments have two stop signs per kilometre, they are both located near a playground or school area, and both met the required criteria as outlined in Chapter 3. From an engineering perspective, it is important to understand what is contributing to the large number of vehicles exceeding the speed limit on one versus the other. Further investigation, which is outside the scope of this research, would be required to gain this understanding. However, Gilmore Avenue appears to be unique when compared with the other study segments. A possible explanation of the higher vehicular speeds on Gilmore Avenue is that it may be being used as a time saving short cut and motorists are increasing their speeds to further increase the amount of time saved. Gilmore Avenue is located between Springfield Road and PTH 101. Springfield Road is the last east-west Regional street prior to the City of Winnipeg limits. Motorists may use Gilmore Avenue as an alternative to Springfield Road. It is not expected that Fleet Avenue is being used as a short cut. Fleet Avenue is located between two east-west Regional streets (Corydon Avenue and Grant Avenue).

Another possible explanation may be that the roadway characteristics on Gilmore Avenue provide greater sight lines. The intersecting roads on Gilmore Avenue are mostly three legged intersections, therefore drivers only need to look one way for opposing traffic. Gilmore Avenue consists of residential fronting properties whereas Fleet Avenue consists of residential flankage properties. Residential flankage homes are located closer to the roadway than residential fronting homes. As well, the roadside landscaping is less developed on Gilmore Avenue, thus further enhancing sight lines. The greater sight lines on Gilmore Avenue may encourage faster speeds as drivers have better visibility of cross street/driveway traffic.

Gilmore Avenue appears to be unique due to its roadway location and roadway characteristics. Figures 4.6 to 4.11 show that by removing Gilmore Avenue from the analysis, there is a trend of speeds increasing at midblock locations when comparing segments with two stop signs per kilometre to segments with greater than two stop signs per kilometre.

In addition to this observation, the analysis also revealed the following:

- The posted speed limits and the 85th percentile speeds are within less than 10 km/h of each other for each of the studied cases. This would imply that the posted speed limit is appropriate for these road segments.

- Day of week does not affect mean or 85th percentile vehicular speeds for any of the analysed cases.

- Time of day does not affect mean or 85th percentile vehicular speeds for any of the analysed cases.

- Depending on the analysed case, anywhere between 17 % and 52 % of vehicles are travelling over the speed limit of 50 km/h. Gilmore Avenue was found to be the segment where most speeding takes place (52 % of vehicles travel over 50 km/h and 7 % travel over 60 km/h).

- There are differences in the percentage of vehicles travelling greater than the posted speed limit of 50 km/h based on day of week. Road segments with three stop signs per kilometre exhibit a lower number of speed violations during weekends than during other days of the week. This is contrary to the situation observed for segments with five stop signs per kilometre, where weekends experience a higher percentage of speed violations than other days of the week. Further engineering analysis would have to be conducted to fully understand the reason for these differences. However, a cursory investigation of the area revealed that the weekday versus weekend differences in speed may be related to land use issues. For example, in the case involving segments with three stop signs per kilometre, there is a shopping mall in the vicinity, which could be impacting operating speeds (by reducing them) during weekends as a result of higher activity into and out of the mall during those days. In the case involving segments with five stop signs per kilometre, there is a school area, which may impact the speed of vehicles during times when there is no school activity (i.e., on weekends).

- Time of day does not affect the percentage of vehicles travelling greater than the posted speed limit of 50 km/h for most of the analysed cases. However, Gilmore Avenue shows a larger percentage of speed violations during the PM peak period than during the other two time periods. This may be explained by the prior discussion about Gilmore Avenue's function as an east-west thoroughfare.

- Overall, vehicular speed characteristics vary between different road segments. This variation may be related to traffic engineering issues other than stop sign density. Further investigation may need to be conducted to fully understand the causes of these variations.

The analysis involving driver compliance with stop signs found the following:

- There is a large number of violations of stop signs, regardless of the road segment.

- About one-quarter of drivers comply with stop signs at intersections, and the remaining three-quarters do not comply (either because they roll through the intersection, or because they do not stop at all). This is consistent with the information found in the literature.

- The largest number of stop sign violations was recorded on Fleet Avenue (82 %), and the smallest number of violations was recorded on Roch Street (63 %). The largest number of vehicles complying with stop signs in terms of voluntarily stopping was recorded on Betsworth Avenue (21 %), and the smallest number of voluntary stops at stop signs was recorded on Roch Street (3 %).

5.0 CONCLUSIONS

The research is an analysis of vehicular speed characteristics at midpoint between stop signs as a function of stop sign frequency per length of road in an urban setting. The purpose of analysis is to reveal issues that should be considered during the decision making process regarding stop sign density and its impact on speed. The results from this research can be used by transportation engineers to further understand vehicular speed characteristics at midpoint between stop signs as a function of stop sign density and driver compliance at stop controlled intersections.

This chapter presents findings of the research for each of the following: (1) literature review pertaining to stop signs in urban areas; (2) design, development, and implementation of the data collection programs used in this research; and (3) analysis of vehicular speed characteristics at midpoint between stop signs and driver compliance with stop signs. The chapter also addresses future research opportunities.

5.1 LITERATURE REVIEW

A comprehensive literature review was conducted to obtain an understanding about the research and background information pertaining to stop signs in an urban area and their impact on traffic operations, safety, and driver compliance with traffic control. The review found that there has been little recent research regarding the impact of stop signs on traffic operations. The areas of interest were stop signs as a traffic control device, multi-way stop sign warrants, safety issues associated with stop signs, vehicular speeds between stop sign locations, and driver compliance with stop signs.

Research findings vary significantly from jurisdiction to jurisdiction, and researcher to researcher. Various researchers have found that stop signs do not effectively reduce speeds, while others found a decrease of 85th percentile speeds between stop signs. Furthermore, some researchers have found that driver compliance with stop signs varies between 5 % and 32 %, depending on the study. Other specific findings are discussed in detail in Chapter 2 of this thesis.

5.2 DATA COLLECTION

A data collection program was designed, developed, and implemented as part of this research to understand vehicular speeds as a function of stop sign density and to analyse driver compliance with stop signs.

Study locations were selected in residential areas with a grid land use pattern. Criteria used to select the study segments were roadway classification; study segment distance; traffic control at end points; roadway cross-section; and the absence of traffic calming, school and playground areas, traffic signals, and at-grade rail/road crossings. Eight street segments were selected for analysis. The eight study segments are located in the north-east and west areas of the city (four segments in each area). Four cases of stop sign densities were studied: two stop signs per kilometre, three stop signs per kilometre, four stop signs per kilometre, and five stop signs per kilometre. The selected study segments are:

1) Fleet Avenue between Lindsay Street and Elm Street (two stop signs per kilometre);
2) Gilmore Avenue between Rothesay Street and Raleigh Street (two stop signs per kilometre);
3) Mathers Avenue between Lindsay Street and Waverley Street (three stop signs per kilometre);
4) Brazier Street between Kimberly Avenue and McLeod Avenue (three stop signs per kilometre);
5) Cuthbertson Avenue between Shaftesbury Boulevard and Southport Boulevard (four stop signs per kilometre);
6) Roch Street between Kimberly Avenue and McLeod Avenue (four stop signs per kilometre);
7) Betsworth Avenue between Cullen Drive and Municipal Road (five stop signs per kilometre); and
8) Louelda Street between Kimberly Avenue and McLeod Avenue (five stop signs per kilometre).

Data collection was conducted during dry roadway and weather conditions. Vehicular speed data was collected by installing road tubes at midblock locations between stop sign pairs on each study segment. Field observations of driver compliance with stop signs at the study intersections were also conducted. The end point intersections of each study segment were identified as the study intersections. All field observations followed the Institute of Transportation Engineers Transportation Engineering Studies Manual.

5.3 DATA ANALYSIS

An extensive analysis of vehicular speed data at midpoint between stop signs was conducted as part of this research to investigate speed distributions at each study location. In addition, an analysis involving driver compliance with stop signs was conducted as part of this research.

A statistical analysis was conducted to identify similarities or differences regarding directional speed distributions for each study segment. The analysis found that from a statistical perspective, the directional speed distributions of only three study segments could be combined. However, from a practical perspective, based on engineering judgment and professional experience with roadway design and traffic operations, this research determined that the directional distributions for all study segments could be combined for further analysis. This resulted in eight road segments with one speed distribution each. The speed distribution was that resulting from combining each of the directions of travel.

Subsequent analysis, combined with engineering judgment, revealed that it was practical to combine the vehicular speed data for most pairs of road segments falling under each of the stop sign density cases, except for the case dealing with two stop signs per kilometre. This resulted in the following cases used in this research for further analysis:

- Fleet Avenue
- Gilmore Avenue

- Three stop signs per kilometre (which combined the bi-directional speeds of Mathers Avenue and Brazier Street)
- Four stop signs per kilometre (which combined the bi-directional speeds of Cuthbertson Avenue and Roch Street)
- Five stop signs per kilometre (which combined the bi-directional speeds of Betsworth Avenue and Louelda Street)

The speed analysis found the following:

- The posted speed limits and the 85th percentile speeds are within less than 10 km/h of each other for each of the studied cases.
- Day of week does not affect mean or 85th percentile vehicular speeds for any of the analysed cases.
- Time of day does not affect mean or 85th percentile vehicular speeds for any of the analysed cases.
- Depending on the analysed case, anywhere between 17 % and 52 % of vehicles are travelling over the speed limit of 50 km/h. Gilmore Avenue was found to be the segment where most speeding takes place (52 % of vehicles travel over 50km/h and 7 % travel over 60 km/h).
- There are differences in the percentage of vehicles travelling greater than the posted speed limit of 50 km/h based on day of week. Road segments with three stop signs per kilometre exhibit a lower number of speed violations during weekends than during other days of the week. This is contrary to the situation observed for segments with five stop signs per kilometre, where weekends experience a higher percentage of speed violations than other days of the week.
- Time of day does not affect the percentage of vehicles travelling greater than the posted speed limit of 50 km/h for most of the analysed cases. However, Gilmore Avenue shows a larger percentage of speed violations during the PM peak period than during the other two time periods.
- Overall, vehicular speed characteristics vary between different road segments. There is no clear relationship between stop sign density and vehicular speeds. Gilmore Avenue consistently shows the highest speeds and Fleet Avenue consistently shows the lowest speeds. Both of these segments contain two stop signs per kilometre. Gilmore Avenue appears to be unique when compared with the other segments due to the speed results and roadway design.

- By removing Gilmore Avenue from the analysis, there is a trend of increasing speeds at midblock locations when comparing segments with two stop signs per kilometre to segments with greater than two stop signs per kilometre.

The analysis involving driver compliance with stop signs found the following:

- There are a large number of violations of stop signs, regardless of the road segment.
- About one-quarter of drivers comply with stop signs at intersections, and the remaining three-quarters do not comply either because they roll through the intersection or because they do not stop at all (about 6:1).
- The largest number of stop sign violations was recorded on Fleet Avenue (82 %), and the smallest number of violations was recorded on Roch Street (63 %). The largest number of vehicles complying with stop signs in terms of voluntarily stopping was recorded on Betsworth Avenue (21 %), and the smallest number of voluntary stops at stop signs was recorded on Roch Street (3 %).

5.4 DISCUSSION OF THE RESEARCH

Available resources limit the amount of research which can be completed. This is a reality of research, but provides opportunities for future research. In this research, there were two issues in particular which required special attention.

Vehicular speed data was collected in speed bins. This shows how many vehicles are travelling within each speed bin, but it is impossible to determine the actual speed of each vehicle at the time when they drove over the tubes. This is a reality of the speed data collection equipment and was taken into account during the statistical analysis, where it was assumed that all vehicles within the speed bin were travelling at the midpoint speed of each given speed bin.

To identify true relationships between vehicular speeds and stop sign density, or between driver compliance with stop signs and stop sign density, it would have to be assumed that all vehicles travelled the complete length of the study segments during the data collection program. However, because of the nature of traffic activity, this is clearly not the case, and poses challenges during data analysis and interpretation.

5.5 FUTURE RESEARCH

The research has identified the following opportunities for further study:

- Analysis of speed characteristics when there is no stop signs along the road segment (i.e. 0 stop signs per kilometre). This may be useful to strengthen the discussion of speed characteristics as a function of stop sign density.
- The effect of weather and roadway conditions (i.e. ice and snow) on vehicular speeds and driver compliance with stop signs.
- The impact of warranted versus unwarranted stop signs on vehicular speed and driver compliance with stop signs.
- Investigation of the collision characteristics at and between stop controlled intersections of various stop sign densities.
- Analysis of driver compliance with stop signs as a function of stop sign density.
- Evaluation of advanced technologies such as adaptive speed control.
- The application of Global Positioning System (GPS) for data collection. Further research may consider recruiting people to drive a specific route which contains all study segments. The vehicle would be equipped with a GPS to record and store the vehicular speeds along the study segments and driver compliance at the stop controlled intersections. This would ensure that motorists drive the complete study segment and would provide actual speeds, as opposed to storing speed data into speed bins.

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APPENDIX: SPEED DISTRIBUTION CURVES AND CUMULATIVE SPEED DISTRIBUTIONS BY DIRECTION

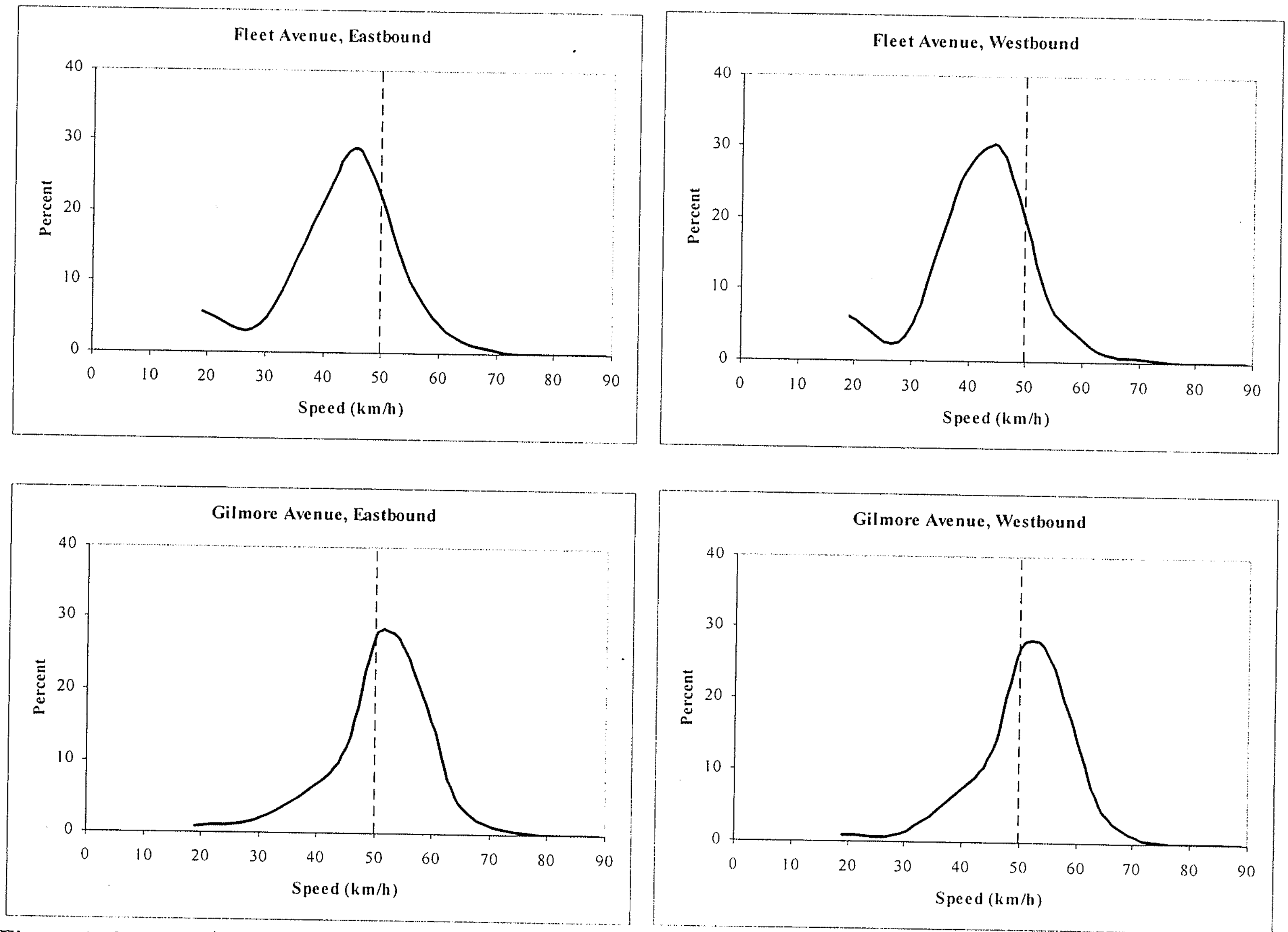

Figure 1: Speed Distribution Curves for Two Stop Signs per Kilometre by Direction

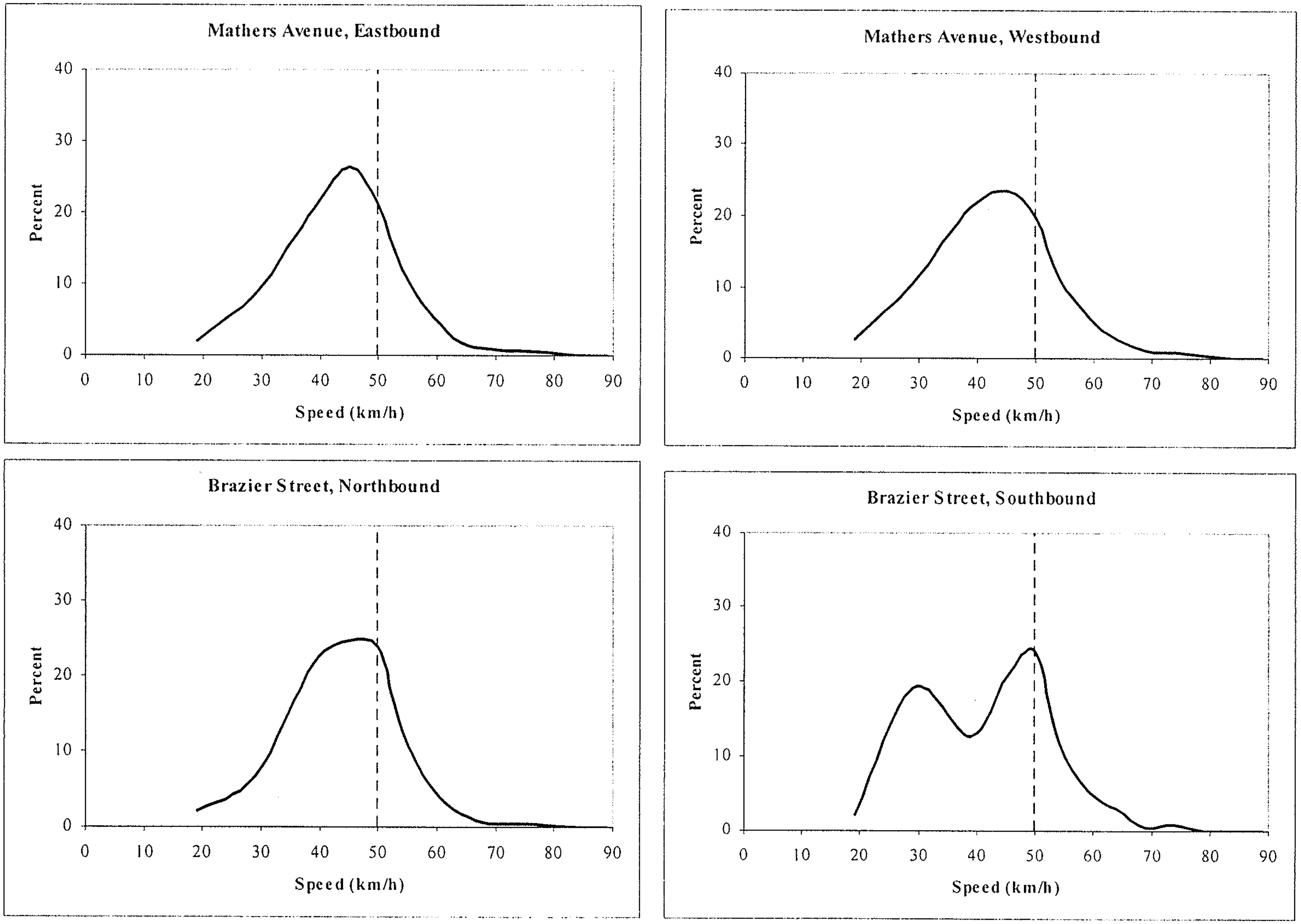

Figure 2: Speed Distribution Curves for Three Stop Signs per Kilometre by Direction

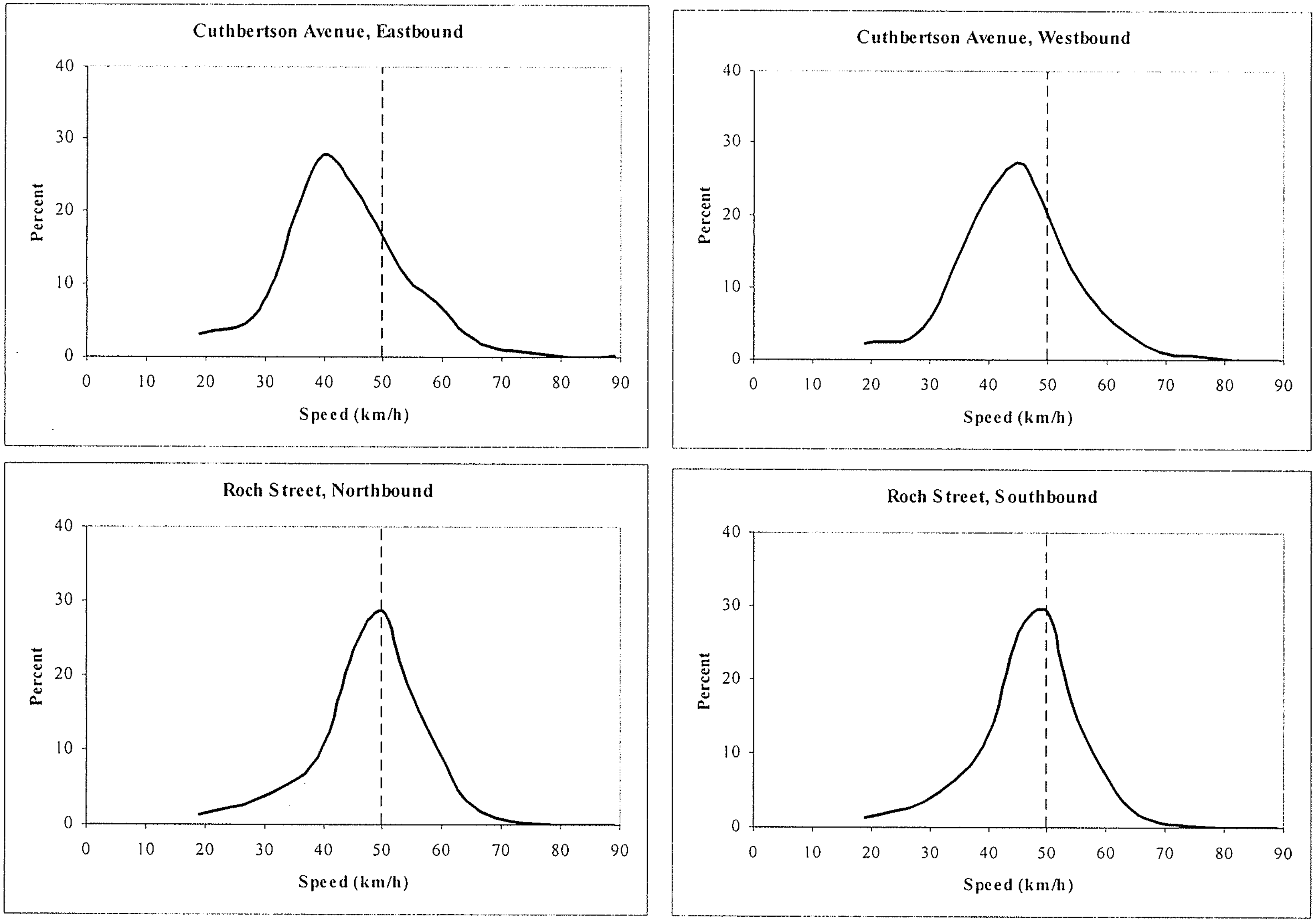

Figure 3: Speed Distribution Curves for Four Stop Signs per Kilometre by Direction

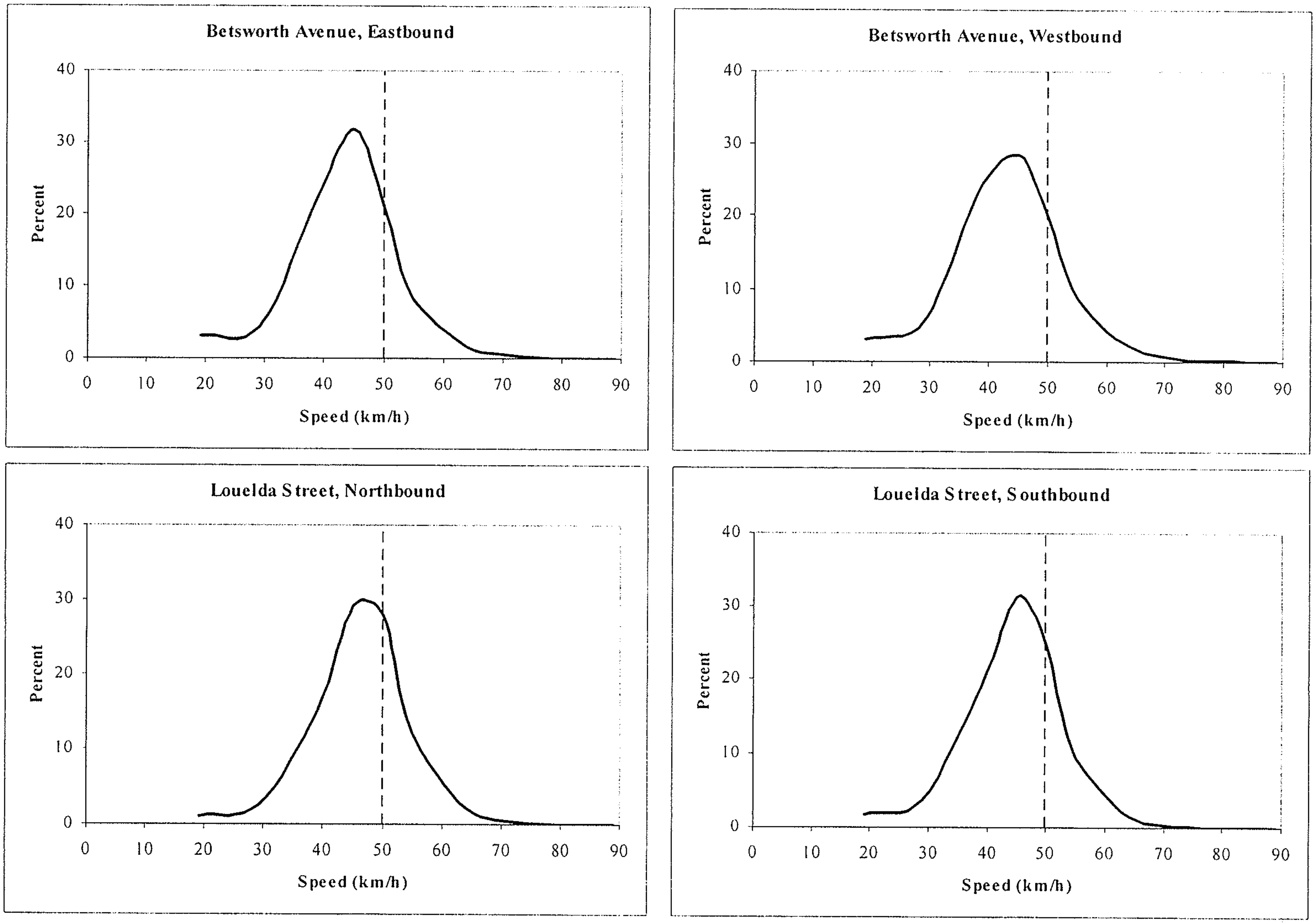

Figure 4: Speed Distribution Curves for Five Stop Signs per Kilometre by Direction

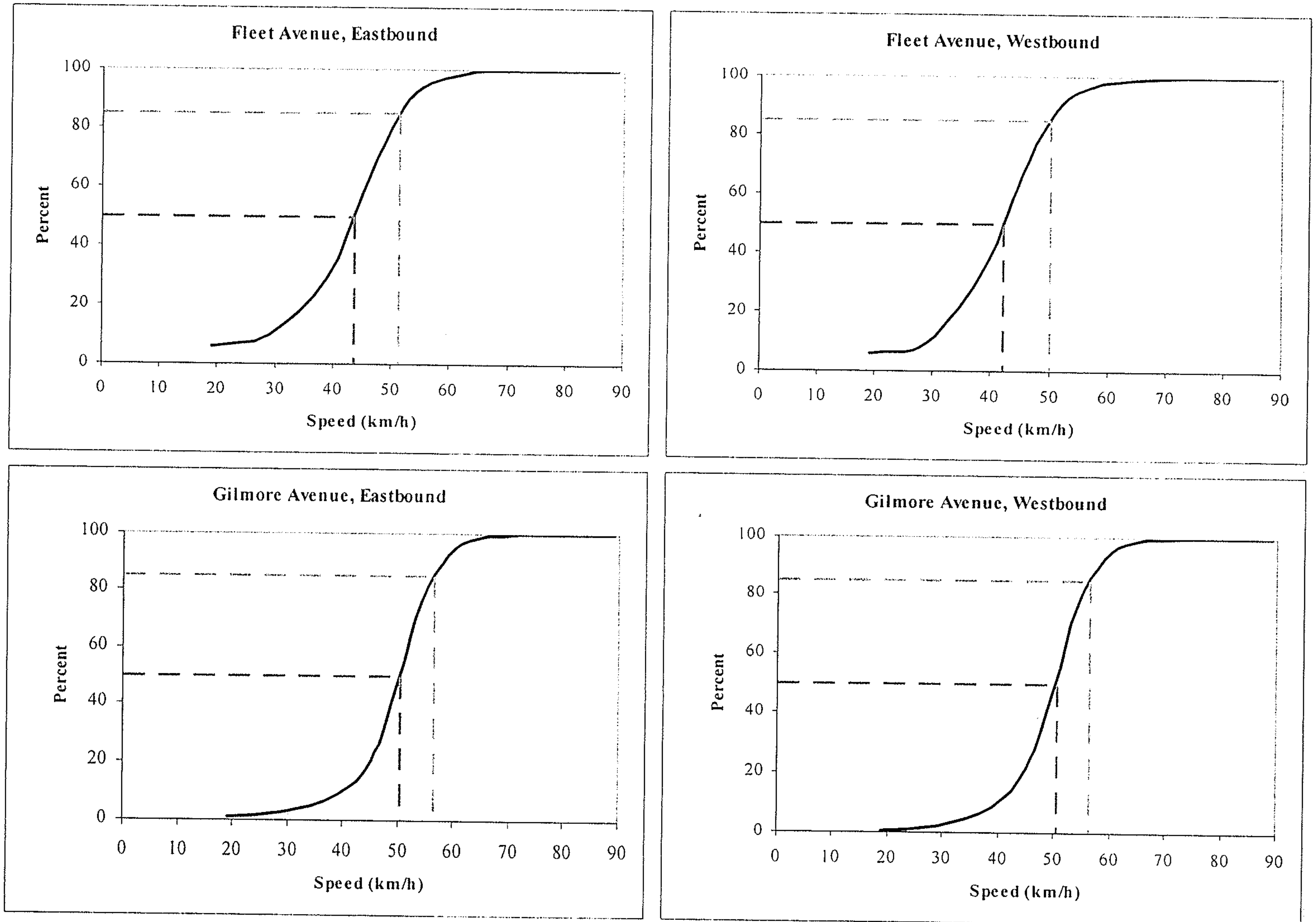

Figure 5: Cumulative Speed Distributions for Two Stop Signs per Kilometre by Direction

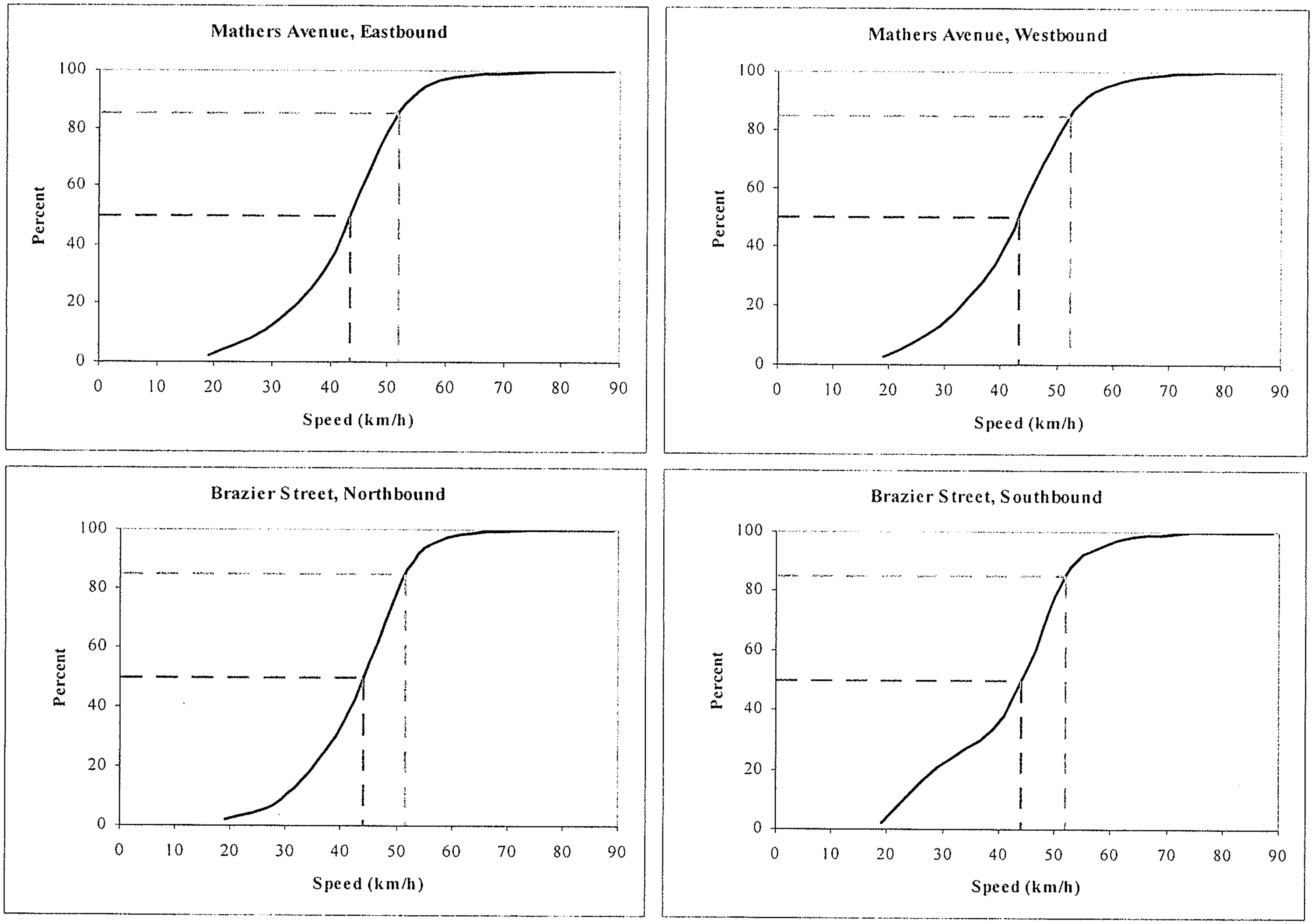

Figure 6: Cumulative Speed Distributions for Three Stop Signs per Kilometre by Direction

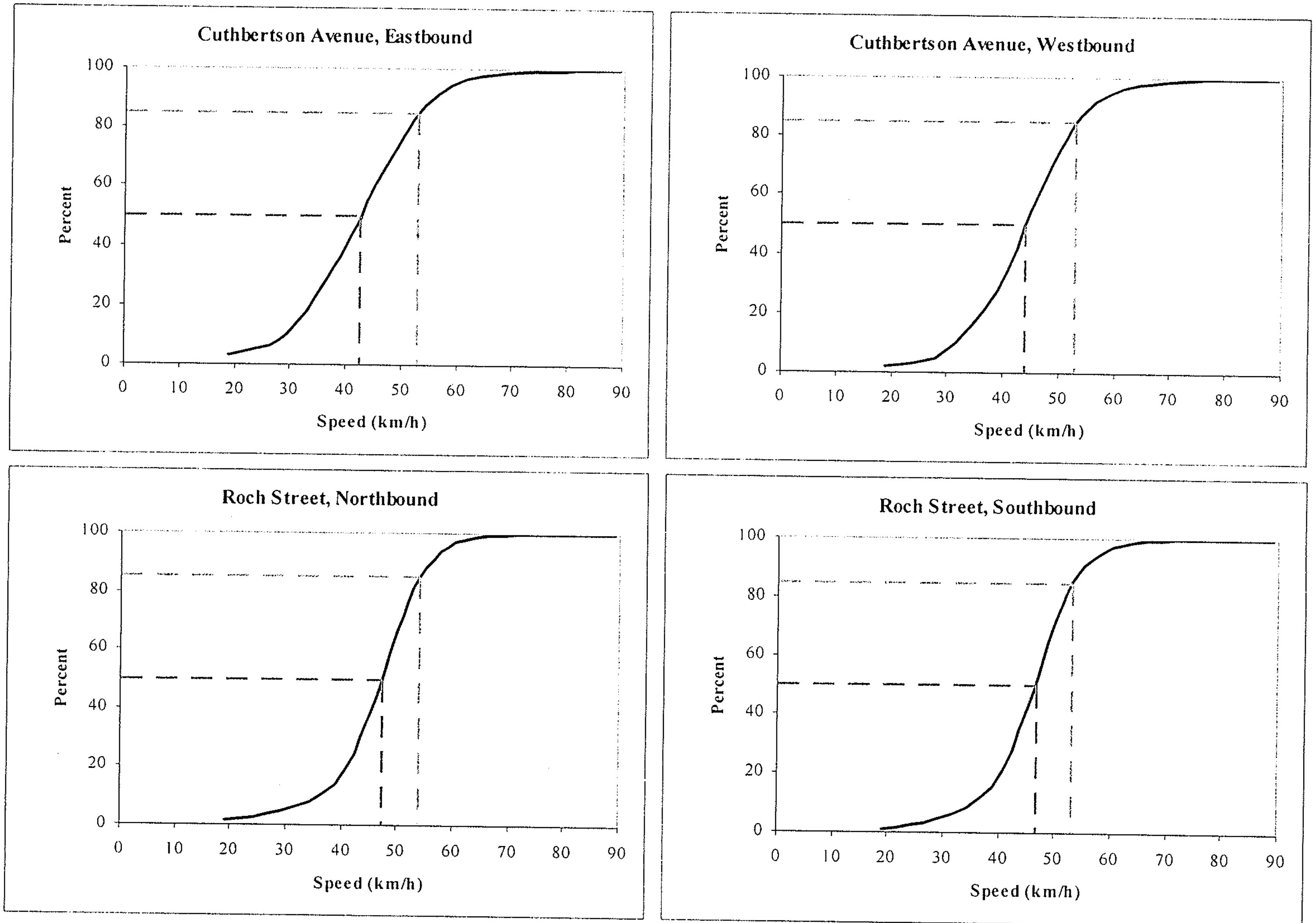

Figure 7: Cumulative Speed Distributions for Four Stop Signs per Kilometre by Direction

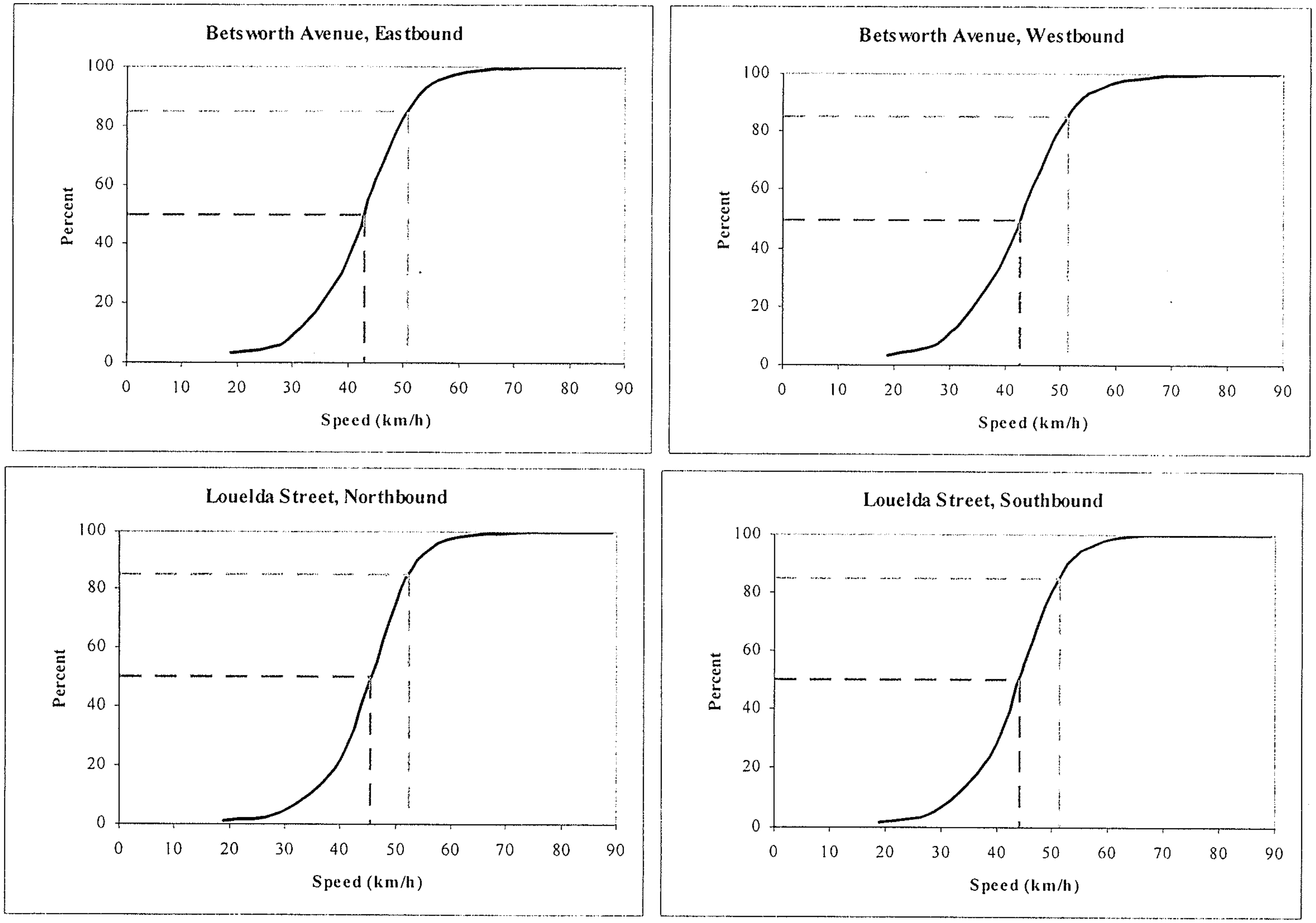

Figure 8: Cumulative Speed Distributions for Five Stop Signs per Kilometre by Direction