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EVALUATION OF PLANNED RESIDENTIAL ENVIRONMENTS WITH REGARD TO PEDESTRIAN SAFETY: A CASE STUDY OF EDMONTON

BY ©

SHUGUANG WANG

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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FACULTY OF GRADUATE STUDIES AND RESEARCH

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also proved that within the planned residential areas of Edmonton, neighbourhoods that were designed as units of larger communities in a hierarchical structure have significantly lower mean pedestrian accident rates than those that were designed as though they were independent or self-contained. Generally speaking, planners have done much to improve pedestrian safety by incorporating the following environmental solutions into their residential designs:

(1) organizing residential streets into functional hierarchies, together with the maximum practicable use of loop streets, culs-de-sac, and T-intersections;

(2) minimizing street density, intersection density and the number of neighbourhood entry points from arterial boundary streets;

(3) reversing peripheral houses so that they do not front on arterial streets;

(4) arranging local service facilities in accordance with their respective service areas so as to minimize the number of streets (especially arterial streets) that pedestrian users have to cross to reach them.

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The thesis would not have been successfully completed without the help from many individuals.

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ensure that my graduate studies would not be interrupted because of financial difficulties; she never "bothered" me with family chores when I needed quite hours to read, to think and to write at home, and never complained for my less than equitable sharing of the household responsibilities.

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CHAPTER 1

INTRODUCTION

1.1 Statement of the Research Problem and the Purpose of the Thesis

> "Ever since an alternative method of land transport to shank's pony was first invented the not-so-fortunate travellers on foot have been at risk. ... Trouble on a much more serious scale came with the arrival on the scene of the motor vehicle. It quickly established its supremacy in door-to-door transport for people and goods and then began its penetration of pedestrian crowded urban streets. The results in almost every city in the world have been a mixture of benefits and disaster. Benefits in the sense that more is done, more is made,and life goes faster; disaster because so many people are killed and injured, noise and pollution and other side effects are rife and because the influence of the motor vehicles calls into question the very principles of city design and the organization of transport" (Buchanan, in Hass-Klau, 1990:xiii).

Within our existing urban forms, residential areas are the most extensive pedestrian activity spaces. Yet, they must accommodate a great deal of vehicular traffic as well. As a result, accidents between pedestrians and motor vehicles occur frequently in residential areas, a point revealed by many researchers (for example: Blackman, 1966; OECD, 1979; Beth and Pharoah, 1988; Tolley, 1989). As Homburger, Deakin, Bosselmann, Smith, and Beukers (1989) remarked, residents place a high value on the quality of life in their neighbourhoods. Traffic is considered as one of the main threats to that quality of life, in large part because of the risk of accidents to people walking to and from their homes. A pedestrian accident occurs when there is unexpected physical contact between a pedestrian and a moving vehicle of any kind. Since accidents may cause mental trauma, bodily injury, or even death to the pedestrian involved, they are matters of great importance to residents. The safety of children and the elderly is a source of particular concern.

There are three general approaches to the improvement of pedestrian safety: education; regulation; and environmental solutions. Education aims at raising the consciousness of both drivers and pedestrians so that they will observe traffic rules and show courtesy to one another, and thus avoid accidents or at least reduce their frequency. Regulation is embodied in enforceable laws, which are usually implemented through the installation of lights and signs to regulate traffic flow and pedestrian movement at their crucial points of contact. Environmental solutions, on the other hand, aim to minimize the accident potential that is inherent in the physical form of the urban environment. This they do through the deliberate manipulation or design of the critical environmental features, such as land use and street networks. It will also be evident from this definition that environment here refers to the "built environment", as that term is commonly used by planners and urban designers (Hodge, 1991:139).

All three approaches are necessary for the promotion of pedestrian safety, but environmental solutions are fundamental. In the first place, appropriate learned behaviours must be supported by visible regulatory devices. But while these devices enhance the awareness of cautious drivers and pedestrians, they do not physically prevent casual ones from violating traffic laws. It is here that physical planning and design assume their significance. It is possible, for example, to arrange homes and local service facilities (such as schools, playgrounds and neighbourhood shopping centres) in such a way that pedestrians do not have to cross heavily trafficked streets to reach their most frequented destinations. Another highly favoured environmental solution is to separate pedestrians from automobiles by designing specially insulated arterial streets or by providing pedestrian footpaths linking homes to various neighbourhood service facilities. As Blumenthal (quoted in Blackman, 1966:2) put it, "The naive approach that places the blame for accidents on human shortcomings alone will be less effective than the approach that recognizes the human-environment interaction and the need for an environment that does not make unreasonable demands on human capabilities, and that is 'forgiving' of inevitable human errors." It must also be recognized that physical development is a long-term business. Whatever is built will generally last for many decades. From a traffic safety perspective, it is difficult to compensate for badly designed environments by regulatory measures alone.

The planning and design of residential environment for pedestrian safety has long been consciously conceived in theory and deliberately tested in practice. This can be traced back at least to the 1920s, when Clarence Perry first formulated his influential "neighbourhood unit" concept and Henry Wright and Clarence Stein applied it in an innovative way to the development of North American new towns. Since then, a variety of planning principles has been formulated to guide the development of safe residential environments. But how successful have these planning efforts been from the standpoint of pedestrian safety? This question cannot be answered from the existing research literature. There have been many studies of the pedestrian safety effects of traffic planning, but they concentrate on such things as the installation of traffic control devices or the implementation of route changes. There have, for instance, been studies of the safety effects of various forms of traffic control at pedestrian crosswalks (Robertson, 1984; Chadda and Schonfeld, 1986; Yagar, 1986; Smith and Knoblauch, 1987), as well as studies of the design or redesign of residential streets for pedestrian safety (Poulton, 1982; Jenks, 1986; Amamoo, 1989; Homburger, Deakin, Bosselmann, Smith and Beukers, 1989; Howe and Alexiou, 1989; Mackey, 1990). By contrast, no studies have been found that systematically and comprehensively investigate the practical effects of the various residential planning principles and their spatial products, the different forms of residential environments. One explanation, as Homburger, Deakin, Bosselmann, Smith and Beukers (1989) have pointed out, is inadequate data. Pedestrian accident records should be the most convincing indicators of problem areas, yet they rarely include the kinds of environmental information, such as neighbourhood type, street type and intersection form, that are needed if pedestrian accident patterns are to be related to variations in the physical form of residential environment.

Traditionally, physical planning principles have focused on guiding environmental design, which refers to the artificial arrangement of the various land use components and transportation facilities into a preferred spatial pattern (Chapin and Kaiser, 1985). Planning principles are derived from the specification of planning ends. They are expressly concerned with what ought to be and, therefore, are normative in nature. As Bolan (1983:4) observed, normative theories do not make explicit predictions about the future, they offer prescriptions about how people ought to act and what should be done. Because of this characteristic, the validity of planning principles can be tested and justified only in real, specific contexts.

With this in mind, the thesis research was designed as a comprehensive evaluation of those residential planning principles that bear most directly on the issue of pedestrian safety and have had strong influences on the formulation of environmental solutions, using Edmonton as a practical laboratory. Edmonton is an appropriate choice because of its size and its diversified residential environments, and also because reliable data on pedestrian accidents are available.

These data do not clearly distinguish the type of built environment in which each accident was reported, but that critical information could be recovered from other sources. This is a big advantage of the case study. The basic objective of the thesis research is to discover which of Edmonton's various forms of residential environment is safest for pedestrians; and, as a corollary to that, to determine whether some residential areas are safer than others because of the particular environmental solutions that were incorporated into their designs. By evaluating past practice in this way, we can better understand the nature of both success and failure, so that we can build on the successes of the past and avoid repeating old mistakes.

1.2 Organisation of the Thesis

This thesis consists of 9 chapters:

Chapter 1: Introduction

This chapter states the research problem and the purpose of the study.

Chapter 2: Conceptualization of the Thesis Research: A Theoretical Background

Chapter 2 provides a theoretical background for the conceptualization of the thesis research. It has three general purposes: (1) to review the concept of residential areas as pedestrian activity spaces; (2) to generalize about the characteristics of pedestrian accidents from the research done by others and their planning implications; and (3) to describe

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Chapter 8: Pedestrian Accidents and Local Environmental Configuration

While certain forms of streets and intersections are assumed to be more hazardous than others, not all streets and intersections of the same form should be expected to court equally significant numbers of accidents. In other words, although neighbourhoods of the same type have the same generalized street patterns, it does not follow that they will all be equally safe or unsafe. Pedestrian accidents are attributable not only to street patterns but also to the intensity of vehicular traffic and pedestrian flows, which in turn are influenced by the spatial arrangement of vehicular and pedestrian trip generators, a feature of land use organization. Since neighbourhoods in each of the five categories in Edmonton vary in their detailed forms, the effects of differences in their local configuration must be investigated as well. The purpose of this chapter therefore is two-fold: first, to discover if there are significant differences in pedestrian accident rates among the individual neighbourhoods of each type; and second, and more importantly, to determine what specific features of local environmental configuration are associated with a relatively high incidence of pedestrian accidents in each neighbourhood type, and whether these same features also provide explanations for some of the between-type variations in pedestrian accident rates.

Chapter 9: Conclusions and Recommendations

This chapter draws conclusions from the research findings and provides recommendations for future residential planning and design.

CHAPTER 2

CONCEPTUALISATION OF THE THESIS RESEARCH: A THEORETICAL BACKGROUND

The primary purpose of this chapter is to construct the conceptual framework that will be used to evaluate the relative effectiveness of the environmental solutions that planners have employed to combat the hazards of pedestrian travel in residential areas. Specifically, the chapter serves three ends. First, it presents a brief review of the concept of residential areas as pedestrian activity spaces. This has important implications for residential planning and design because the spatial patterns of pedestrian activity, and hence the potential for pedestrian accidents, should be influenced by the way that transportation facilities and local service facilities (major pedestrian trip destinations) are organized in relation to dwellings of different types (primary pedestrian trip origins). The second end is to generalize about pedestrian accident characteristics and their planning implications, in so far as these have been investigated in previous research. The main concern here is to determine what other scholars have concluded about the role of the built environment and environmental design in pedestrian accidents, and to identify the research gaps that remain to be filled. Third, and most important, the chapter describes the various environmental solutions that have been favoured by planners, concentrating on those that are most relevant to the problem of pedestrian safety in the residential areas of North

American cities. The general intent is to identify the design concepts and planning principles that have been devised at different times with the aim of creating different forms of residential environment, each form representing a distinctive type of pedestrian activity space with its own characteristic set of environmental solutions.

2.1 Residential Areas as Pedestrian Activity Spaces

Walking is a major mode of urban transportation. As Hillman and Whalley (1979:1) stated, "It is a well known fact, though usually unquantified, that nearly all personal travel involves walking, either as the sole means of travel on a journey or as one or more of its stages." Since personal travel patterns also tend to be closely associated with place of residence, it follows that the residential areas of cities are likely to be important pedestrian activity spaces in their own right, whether for whole trips or just for some stages.

The need for pedestrian travel in residential areas, or "living areas" as Hodge (1991) calls them, arises in large part from their basic structure. "The main function of a residential area," wrote Tolley (1989:5), "is to house people and to provide the everyday necessities of life. As well as homes, we would expect to see schools, clinics, shops and social and religious institutions, with perhaps some offices, businesses and small factories in addition". To realize the "everyday necessities of life", people make trips, most of which emanate from or converge on their homes. The physical distances of these trips are determined by the locations of relevant facilities and services, which affects the choice of transport mode as well. Usually, long trips are made in vehicles of one kind or another, while short trips may be made on foot because walking is cheaper and often more convenient than using a vehicle; in some circumstances, it may be the only feasible mode. Pedestrian access to services in residential areas is therefore most important at the local or neighbourhood level, the term "neighbourhood" being used here in the physical planning sense of "the geographic area within which residents conveniently share the common services and facilities needed in the vicinity of their dwellings" (O'Mara, 1978:115). Following from this definition, which will be adhered to throughout the thesis, the neighbourhood will also constitute the basic residential unit for purposes of the research problem.

Within residential areas in general, homes are the primary origins of pedestrian trips and the various neighbourhood service facilities are normally the destinations (Figure 2.1). In some cases, however, destinations can become secondary origins. That is, pedestrians may walk from one neighbourhood facility directly to another. For example, students may walk to neighbourhood shops from their schools during lunch breaks, or to a neighbourhood park on their way home. In other cases, service facilities are not the destinations at all.

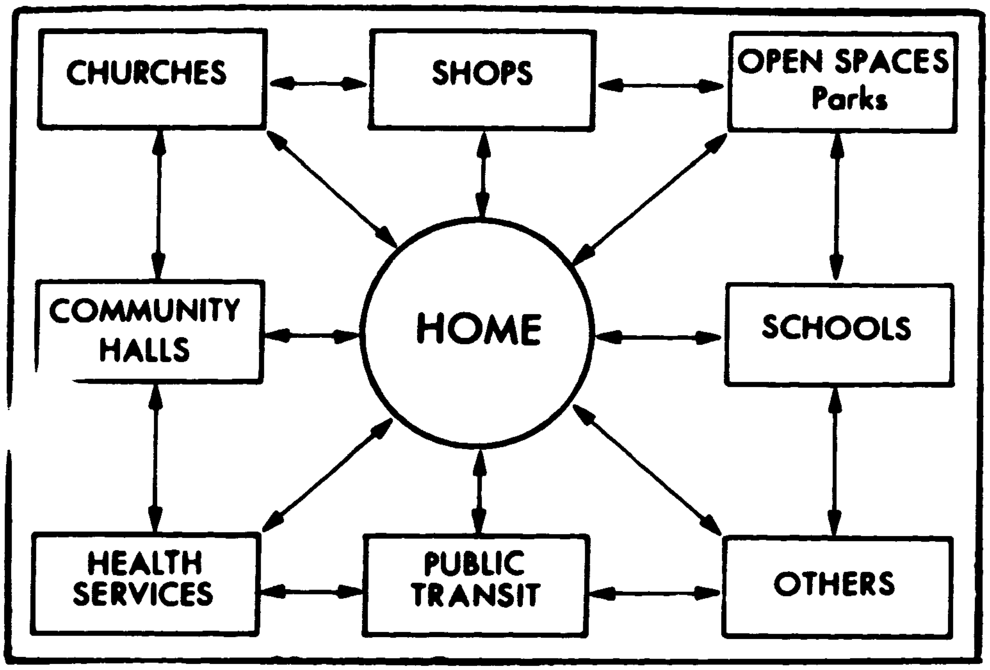

Figure 2.1 Theoretical patterns of pedestrian movement in residential areas

People walk between houses when making visits to neighbours, for example, and increasingly they walk in the vicinity of their own homes for leisure and health purposes (Wickert, 1993). As a result, pedestrian movement patterns in residential areas are quite complex.

All people walk at some time in their home areas, but children and elderly people are believed to walk more than other age groups (Mackey, 1990). This is evidenced by Hillman and Whalley's research in the United Kingdom. Figure 2.2 (see the heavy solid line) shows that most journeys made by children (18 and under) and the elderly (65 and over) are pedestrian trips, while adults (19-64) make more journeys by automobile than on foot. Hillman and Whalley's data do not indicate what proportions of pedestrian trips take place in residential areas but it is reasonable to presume that they are high, especially among children and the elderly.

Children commonly walk to schools in or near their home neighbourhoods on weekdays. School journeys are necessary trips, which are independent of weather and the spatial arrangement of pedestrian connections between houses and schools. Returning home at lunchtime is also common among those who walk to school and live close to it. Many children thus make at least four walking trips a day. Then, after school or on weekends, they may walk to nearby parks or playgrounds or to local shopping malls for recreational activities.

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Figure 2.2 Proportions of all journeys made by different aged people with different transport modes in the United Kingdom

Source: Hillman and Whalley, 1979:34

Elderly people walk in their neighbourhoods for various reasons. They may walk to shops (perhaps with a shopping cart) because their physical ability to drive declines. They may take casual strolls for health or pleasure purposes, and they frequently walk to community centres, to churches, and to neighbours for recreational, religious, and social purposes. Since the elderly are mostly retired, they have more time to spend on walking than employed people. Younger adults, on the other hand, are mostly involved in employment outside the residential areas where they live. Their work trips are usually made in their own vehicles, so they do not walk in their neighbourhoods as much as children and the elderly do (Wickert, 1993). Those who do not drive will have to walk to and from a nearby transit stop as part of their journey to work, but this group of people is not normally as large as those who drive to work, especially in North American cities.

These observations also serve to underscore the obvious fact that residential areas must accommodate vehicular traffic as well as pedestrians. First of all, most families in North American cities own private vehicles. According to the Edmonton Journal (November 12, 1990), the rate in Edmonton in 1989 was 1.42 vehicles per household. People drive at least some distance within their neighbourhoods when they go out and come home. Second, individual households have frequent needs for the delivery of goods and services and for waste collection. This includes emergency services, such as fire trucks, ambulances and police vehicles. Third, regular public transit commonly needs to penetrate residential districts to collect and deliver passengers near their homes. Residential streets must therefore perform a number of transport functions, accommodating both vehicular traffic of various kinds and pedestrian movement. This means that while residential areas are planned as important pedestrian activity spaces, there is always some potential for conflict between pedestrians and vehicles on residential streets, conflict that gives rise to pedestrian accidents.

2.2 Characteristics of Pedestrian Accidents

Although it is widely acknowledged that pedestrian accidents are a reasonably common occurrence in residential areas, there is little systematic information about their incidence or causes, because accident data are not often reported in an appropriate form. As Homburger, Deakin, Bosselmann, Smith and Beukers (1989:18) observed, "It is difficult to analyze accidents in residential areas scientifically. Most underlying data do not clearly distinguish the type of area in which accidents were reported". Tolley (1989:7) made essentially the same point in reference to fatal accidents: "Though it is known that some 80 per cent of pedestrian fatalities in Britain occur on built-up roads [i.e. roads on which buildings front directly], statistics are not available separately for residential areas". This does not mean that nothing is known about accidents in residential areas, but the available information tends to be local and piecemeal. As a consequence, studies of accidents on residential streets do not necessarily present their findings in a consistent fashion or even use consistent terminology. They may not include all the accidents that should properly be attributed to residential areas either. One particularly important issue is that accidents on arterial or through streets are commonly disregarded, despite the fact that these streets often traverse residential districts from which they draw much, if not most, of their pedestrian traffic.

The purpose of this section is to review briefly what is known about those characteristics of pedestrian accidents that are most pertinent to the thesis research. These characteristics are of three kinds: the temporal and seasonal variability of accidents; the age-groups that are most at risk; and the features of the built environment with which pedestrian accidents have been associated in other studies. The effects of modifying these features will be considered as well, since they represent particular environmental solutions that have been adopted in practice. As far as possible, the review will focus on characteristics that relate directly to residential areas.

2.2.1 Temporal and Seasonal Distribution of Pedestrian Accidents

Figure 2.3 shows the temporal and seasonal distribution

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Figure 2.3 Daily journey rates and pedestrian casualties according to day of week, time of day, and month of year in the United Kingdom

Source: Hillman and Whalley, 1979:28

of pedestrian accidents in the United Kingdom in relation to variations in the volume of vehicular and pedestrian traffic. Hillman and Whalley (1979) made the following observation when interpreting this graph: recorded pedestrian accidents rise and fall in general consonance with the rise and fall of motorized journeys and journeys on foot, the incidence of accidents reflecting the incidence of conflict situations. This is especially evident in the afternoon hours (15:00-19:00) when the peak of vehicular traffic lasts for 3-4 hours and pedestrian journeys are at their highest level of the day. Hillman and Whalley also drew attention to the marked increase in pedestrian accidents in the late evening hours and on Fridays and Saturdays, in spite of a reduction in the numbers of pedestrian trips then. This, they suggested, may be partly due to the effects of drinking on both drivers and pedestrians. The rise in the winter they see as being related to the greater likelihood of ice on the roads and of vehicles skidding, though the pronounced peak in December again suggests a connection with excessive drinking, this time over the Christmas season.

Beyond hinting at behavioural and other factors, such as weather and road conditions, that are likely to contribute to pedestrian accidents, Figure 2.3 is chiefly valuable because it confirms the intuitively obvious point that the frequency of accidents is a function of traffic intensity, both vehicular and pedestrian. Traffic volumes are not the only explanation, as witness the sharp contrast in accident frequency between the morning and afternoon peaks, but there is still a strong tendency for accidents to occur at times when both kinds of traffic are at high levels and the potential for conflict between them is correspondingly great. It is in this simple fact that environmental solutions find their essential justification. Although they cannot be expected to eliminate conflict entirely, let alone prevent careless or irresponsible behaviour, they can be used to limit the situations where either drivers or pedestrians might put themselves at risk.

2.2.2 Age Groups Particularly Vulnerable to Accidents

Several studies have shown that children and elderly people are particularly vulnerable to pedestrian accidents. In a study of over 2,000 pedestrian accidents in 13 American cities, for example, it was found that more than half involved youngsters under 15 years of age (Snyder and Knoblauch, 1971). A comparable British study reported that children up to the age of 14 accounted for 42 per cent of pedestrian casualties although they comprise only 24 per cent of the population (Hillman and Whalley, 1979). As for the elderly, the American Automobile Association (1965a) found that 40 per cent of all pedestrian deaths in the United States involved people 65 years old and over. This implies that when accident victims are elderly, there is a high probability that their injuries will be fatal.

These statistics refer to all cases of pedestrian accidents , wherever they may occur in the city, but there is some evidence to indicate that residential areas are by no means safe for pedestrians at either end of the age scale. Thus, Dutch studies found that the proportions of accidents involving children and elderly people are indeed greater on residential streets than on other streets, and that most accidents affecting children occurred in the vicinity of their homes. Similarly, in Germany, it was determined that 55 per cent of the accidents to children pedestrians happened on roads in residential areas, though it is not clear how residential areas were defined in this instance (Homburger, Deakin, Bosselmann, Smith and Beukers, 1989).

The findings from this scattering of accident studies are generally consistent with the pedestrian activity patterns described in Section 2.1: that is, because children and the elderly tend to walk more than people of other age groups, they are most likely to be at risk. There are other factors that make them especially vulnerable, however. For example, children's sense of traffic rules is weak. They often cross streets where they should not, and may use the street for games. Sometimes, they leave sidewalks suddenly and run on to the adjacent street, for which the drivers of oncoming vehicles are unprepared. By contrast, according to Harrell (1990), the elderly are the most cautious of all pedestrians and tend to take appropriate safety precautions when crossing streets. Their vulnerability is a natural consequence of aging. As their vision and hearing deteriorate, for example, their ability to detect oncoming vehicles is reduced. Their manoeuvring actions may be slow too, because of physical infirmities or because they do not react as quickly as they did when they were younger.

In sum, the above characteristics suggest that particular attention should be given to children and the elderly in the study of pedestrian accidents. They also underline the importance of residential planning to meet the special needs of these two vulnerable age-groups, especially in terms of the locations of schools, playgrounds, neighbourhood parks and shopping facilities, and the design of the transport facilities by which they obtain access to these local services.

2.2.3 Pedestrian Accidents in Relation to the Built Environment

Numerous studies have examined the incidence of pedestrian accidents in relation to selected features of the built environment, though by far the greatest attention has been paid to various characteristics of street forms and networks. A useful summary of the main findings and their planning implications is provided by Homburger, Deakin, Bosselmann, Smith and Beukers (1989:18-19). This section is based on their review, supplemented by references to other studies where appropriate. The majority of the published research is from Western Europe, and especially from Germany, the Netherlands and the United Kingdom.

1. "Hazards are greatest on streets where there is much parking, on streets with many intersections, on long, straight streets, on busy streets, and in districts with few playground facilities." This is the broadest of the reported findings and will be revisited in several subsequent points.

2. Undifferentiated street networks, in which all streets are essentially identical, are less safe than hierarchically organized networks, where streets are designed in accordance with their intended functions and the flow of traffic is deliberately channelled. In North American cities, undifferentiated networks most typically take a grid form which is marked by long straight streets and frequent intersections, features that are highly related to the incidence of pedestrian accidents. This finding confirms a long-held belief of urban planners and gives rise to a predictable conclusion: "Strict differentiation of streets according to their function leads to safe residential areas."

3. The highest concentrations of pedestrian accidents occur on arterial streets carrying heavy loads of through traffic (OECD, 1979; Kraay, Mathijssen and Wegman, 1985; Beth and Pharoah, 1988). However, where frontage access onto arterial streets is prohibited, and the layout of adjoining residential areas is such that pedestrians have no need to use arterials as their routes, accident rates are minimised.

4. Within neighbourhoods, the majority of accidents occur

on collector-type roads; that is, roads that carry the main flows of traffic in and out of individual neighbourhoods. The hazard is even greater when such roads bisect a neighbourhood, inviting through traffic in addition to their local traffic loads. The latter situation is most typically associated with undifferentiated networks. Conversely, streets that are deliberately designed to carry light loads of purely local traffic are considerably safer than through streets, as the proponents of hierarchical networks have long argued.

5. Many pedestrian accidents happen at intersections (American Automobile Association, 1965b; Fruin, 1973; Robertson, 1984; Untermann, 1984; Brown, 1986). Pedestrians normally cross streets at intersections, and vehicles arrive from different directions, making pedestrian manoeuvres difficult. This is especially true around uncontrolled intersections where pedestrians and vehicles simultaneously compete for a particular space, which leads to a high accident risk. Even at traffic-controlled intersections, vehicles making turns on a green light, and those making right turns on a red light, may be in conflict with pedestrians. What is not indicated by past studies, however, is the association between pedestrian accidents and different types of intersections.

6. Point 5 to the contrary, Dutch studies found that accidents involving children up to the age of 5 years often occur between intersections on local streets. The risk is particularly great when the streets are heavily used for

parking because "parked cars block the view of the road for children and the view of children for approaching drivers". It is a situation which exacerbates the problem caused by young children's unpredictable behaviour.

7. When pedestrian routes and vehicle routes are fully separated, meaning that they have few if any points of contact, accident rates are "very low".

8. "Road safety is greater in newly built residential districts than in older neighbourhoods". This finding is not explained but it presumably reflects the effects of planning and conscious design. That is, the newer districts were almost certain to have been built in accordance with "a set of clearly stated design ideas or principles" (Beckley,1979:62), including principles that were intended to enhance pedestrian safety.

In general, the above revealed characteristics have two implications for the thesis problem. First, they demonstrate that pedestrian accidents are associated with definite features of the built environment, notably undifferentiated street networks, streets with frequent intersections, arterial streets with unrestricted pedestrian access, and streets carrying heavy traffic into and through neighbourhoods. These are also features that planners have long presumed to be unsafe for pedestrians and have therefore aimed to improve. Following from this, as the second implication, it appears from the available research that it is possible to increase pedestrian safety by consciously manipulating the built environment through planning and design. Measures such as differentiating streets in accordance with their intended functions, restricting frontage pedestrian access onto arterial streets, or fully separating pedestrian routes from those of vehicles have particularly been identified. They are all examples of environmental solutions that planners have devised and been able to implement in residential development.

Despite the value of these findings, however, research into the relative effectiveness of the various environmental solutions is still inadequate, especially in North America. It is not just that the published studies reviewed here were largely European; they also concentrated on limited aspects of street form and pattern, whereas the environmental solutions employed by planners cover a broader range of features. In addition to street design in all its aspects they include land use arrangement, block format and the provision of special pedestrian facilities. Yet, no study was found that systematically investigates the safety effects of these other features, especially as they have typically been combined to create different forms of residential environment. In Section 2.1, for example, it was described how various neighbourhood facilities are required to complement homes for satisfying residents' needs in their daily lives. The location and spatial organization of these facilities in relation to dwellings and traffic routes have a direct influence on the numbers and types of streets that pedestrian users must cross to reach them from their homes, and hence on the likelihood of accidents occurring. As the Chicago Planning Commission (1943) recognized 50 years ago, pedestrian accident hazards are not necessarily the fault of those who design the individual elements of the pedestrian environment; rather, they may reflect weaknesses in the comprehensive plans through which these elements are supposed to be coordinated. Among environmental solutions, therefore, we must consider the overall form of residential areas as well as the individual features of their built environment. In the thesis, the former will be referred to as "environmental configuration" and the latter as "design elements".

2.3 Environmental Solutions: Design Elements and Environmental Configurations

According to Cross (1965:79), residential areas in North American cities are organized and subdivided (or configured) on the basis of 4 design "criteria" or elements: land use pattern, street pattern, block pattern and lot pattern. To this list must be added the form of pedestrian circulation network, an element that has been a conscious consideration in planned residential environments. Except for lot pattern, which will be omitted for thesis purposes, all of these design elements affect vehicular and pedestrian circulation and the potential for conflict between them. They therefore have a direct bearing on pedestrian safety. For example, the land use pattern determines the spatial arrangement of traffic generators; the street pattern influences traffic routes in relation to dwellings and local facilities; the block pattern affects the length of streets and the numbers of intersections; and the pedestrian facility network influences pedestrian flow patterns. In addition, each of the above elements has a number of alternative forms which differ in their safety implications. It is these critical design elements in their alternative forms that planners manipulate concretely as individual environmental solutions. However, design elements do not exist in isolation; they are all necessary components of any residential subdivision, and it is through the different combinations of their alternative forms that the various types of residential environment are constituted. Each type is distinguished by a unique configuration, which refers, in this context, to the relative disposition or arrangement of the elements that constitute the residential built environment and the external form that results from this arrangement.

In light of this definition, this section has two purposes. First, it describes the principal forms that each of the critical design elements can take and then discusses their safety implications as individual environmental solutions. Second, it reviews the planning principles and design concepts that have been followed to guide alternative combinations of the several design elements, each combination resulting in a typical general configuration incorporating a particular set of environmental solutions that planners have favoured at some time.

2.3.1 Environmental Design Elements

The 4 design elements that are critical to the configuration of the pedestrian environment (i.e. land use pattern, street pattern, block pattern and pedestrian circulation network) are reviewed in this section. The elements are defined and the safety implications of their alternative forms, as they have been envisaged by planners, are described.

2.3.1.1. Land Use Pattern

In residential areas, the land use pattern refers to the spatial arrangement of local service facilities in relation to housing of various types. The American Public Health Association (1949:42) listed five major types of facilities that should be provided in residential areas. These are:

(1) educational facilities, including kindergartens, elementary schools and high schools

(2) outdoor recreational facilities, such as parks, playgrounds, and informal open spaces

(3) indoor social and cultural facilities, such as churches, libraries and community meeting halls

(4) shopping facilities, including grocery and drug stores, and personal and financial services (e.g. banks, hairdressing salons, and dry cleaning outlets)

(5) health services, such as medical and dental clinics.

In existing residential areas, it can be observed that local service facilities are often organized into different patterns. Take shops and commercial service outlets for example. In some cases, they are arranged in linear forms along traffic thoroughfares (called commercial ribbons); in others, they are grouped in designed clusters as shopping centres and set back from their flanking streets. In general, commercial ribbons are a feature of unplanned residential areas. Their main characteristic for the purposes of the thesis is that pedestrian shoppers frequently have to cross from one side of the street to the other to patronize different shops, thus exposing themselves to the hazards of fast-moving through traffic. Shopping centres, on the other hand, are deliberately designed to facilitate easy and safe pedestrian movement between stores in the same cluster.

Functionally, service facilities in residential areas typically fall into hierarchies. The most obvious examples are retailing and educational facilities. For the former, there are (from low to high) convenience stores, neighbourhood shopping centres, and district and regional centres (Gallion and Eisner, 1980). With regard to the latter, there are (from low to high) elementary, junior high and senior high schools. Normally, facilities at lower levels of a hierarchy have lower population thresholds (i.e. the minimum population needed to support them) and serve smaller areas, thus there are more of them; in contrast, those at higher levels require higher thresholds and serve larger areas, so there are fewer of them. Service facilities of all kinds can vary in their spatial organization as well. In some areas, they are located randomly without any obvious order; in others, they are deliberately organized in relation to their respective service areas. The latter form of organization, which is a mark of conscious planning, should provide better access to services for the majority of intended users, especially pedestrian users.

The five types of facilities listed above are regarded as compatible land uses in residential areas because they complement homes to provide the "everyday necessities of life" for local residents. However, some residential areas have also to accommodate incompatible land uses, such as industrial complexes, transportation terminals, municipal sports facilities and post-secondary education institutions, which have little to do with satisfying "everyday necessities". These facilities often have city-wide service areas and are usually automobile-oriented, hence generating considerable amounts of external traffic for the residential areas in which they are located. Even district or regional shopping centres can become incompatible land uses when poorly integrated with their neighbouring residences, because their service areas extend beyond their immediately surrounding neighbourhoods and they draw external traffic to these neighbourhoods. Due to the extra traffic, residential areas affected by incompatible land use can be expected to have a higher potential for pedestrian-vehicle conflict than those areas where incompatible land uses are deliberately avoided.

Alternative forms of land use organization will be considered in more detail in Section 2.3.2, when various concepts for the configuration of residential areas are reviewed.

2.3.1.2. Street Pattern

Street pattern is characterized by both geometric layout and functional organization. In terms of layout, in most general terms, there are grid streets and curvilinear streets; with regard to organization, streets can form either undifferentiated networks or functionally differentiated hierarchies (see Table 2.1).

Table 2.1 Alternative street patterns

geometric layout	Functional organization	
	Undifferentiated grid network	Differentiated grid network
	Undifferentiated curvilinear network	Differentiated curvilinear network

In undifferentiated networks, all streets are designed with equal carrying capacity. Although such networks are most often associated with grid streets in old residential areas (Figure 2.4), they can be formed from curvilinear streets as well. An early example is provided by the suburb of Riverside in Illinois, designed by Frederick Law Olmsted and Calvin Vaux in 1869. At that time, curvilinear networks were favoured for aesthetic and psychological reasons rather than functional ones, to "imply leisure, contemplativeness and happy tranquillity" (Kostof, 1991:74). The aesthetic justification continues to be important with planners; by and large, curving streets are considered to be more attractive than straight ones, especially in residential areas.

In functional hierarchies, streets differ according to purpose and prescribed traffic volume. While functional hierarchies can be formed with grid streets (Houghton-Evans, 1975:141-146), they are mostly preferred to employ curvilinear streets which, in addition to their aesthetic value, tend to close vistas and hence limit the distance that motorists can see ahead. This is believed to discourage speeding, which is especially important on low-level residential streets fronted by dwellings, where high speed is dangerous. In planned residential areas, the curvilinear street hierarchy has long been the norm for the layout of vehicular circulation systems at the neighbourhood level.

Table 2.2 shows a general classification of urban streets

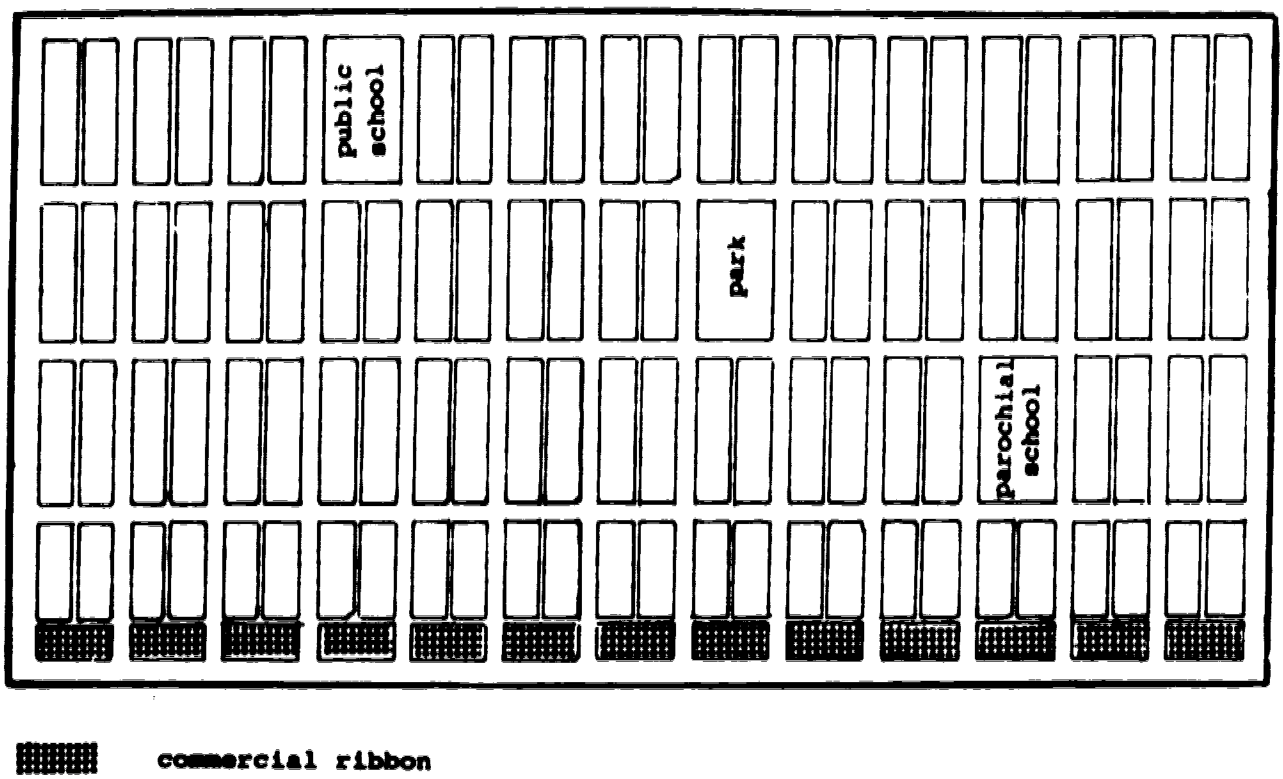


Figure 2.4 Illustration of undifferentiated grid subdivision

Table 2.2 Street classification and preferred design features

Street category	Function and design features	R.O.W. width	Speed limit
Freeways and expressways	Provide regional and metropolitan continuity and unity; with limited access; no grade crossing.	60-90m; 4 or more lanes with median strip.	80 km/h
Major arterial streets	Provide unity throughout contiguous urban areas; usually form neighbourhood boundaries, with channelized intersections; parking generally prohibited; require sidewalks separated from curbs by planting strips; should have no residential lots fronting on them.	36-45m; four lanes with median strip	60 km/h
Minor arterial streets (or major collector streets)	Occasionally form neighbourhood boundaries; stop signs on side streets; require sidewalks separated from curbs by planting strips; may have residential lots fronting on them.	24m; 2 lanes usually undivided.	60 km/h
Collector streets	Main neighbourhood interior streets; with parking lanes; also accommodate public transit; require sidewalks; planting strips are desirable; can provide frontage and access to residences.	18-21m; 2 lanes undivided.	40-50 km/h
Local streets (or access streets)	Provide direct access to dwellings; include short-loops and culs-de-sac; non-conductive to through traffic; street parking is permitted; sidewalks are optional, especially on culs-de-sac.	15-20m; 2 lanes undivided	<40 km/h

Source: adapted from Gallion and Eisner, 1980; American Society of Civil Engineers, National Association of Home Builders and the Urban Land Institute, 1990.

with prescribed functions and preferred design features; an actual layout combining hierarchical structure with curvilinear form is illustrated in Figure 2.5. The designated carrying capacities and speed limits of the different classes of streets decrease progressively from freeways to arterials to access streets, and their design features vary correspondingly. It must be pointed out, however, that design prescriptions and standards are never static; planners and engineers revise them in response to the ever-changing traffic situations in North American cities. As a result, streets of the

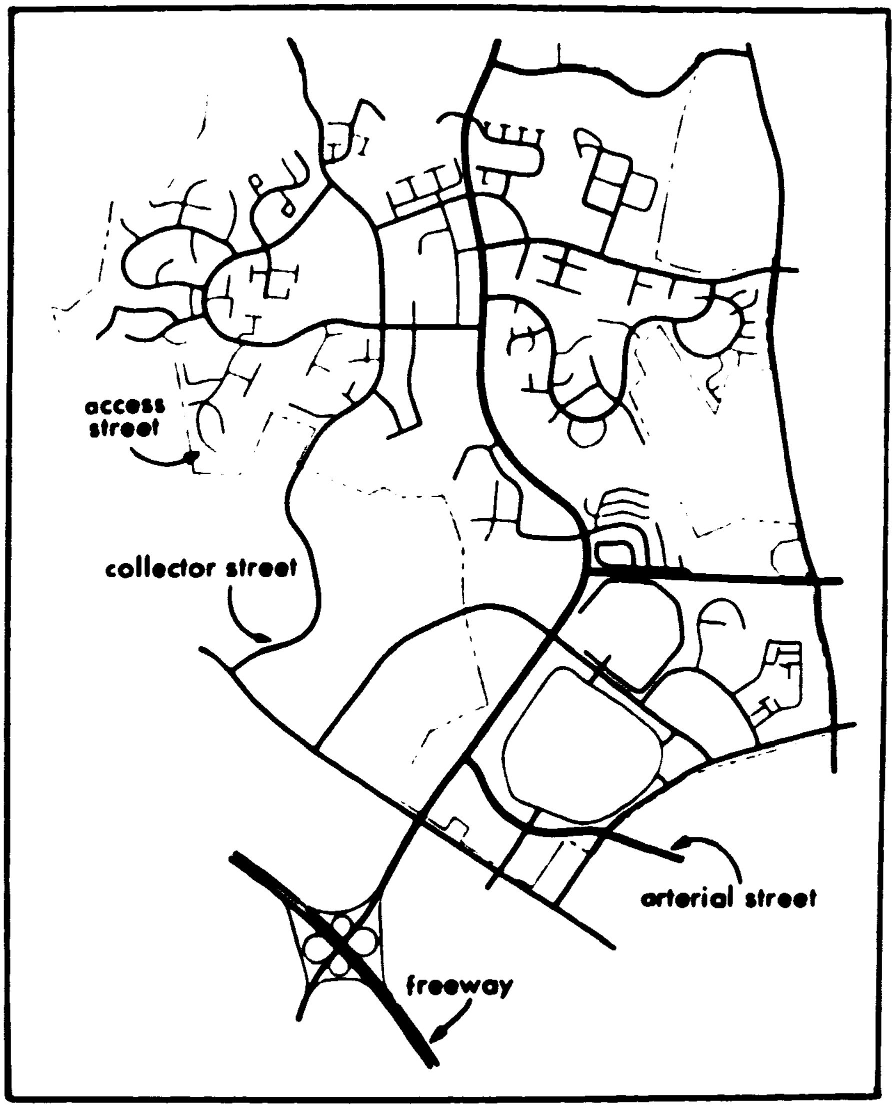


Figure 2.5 A curvilinear street hierarchy in Montgomery Village, Maryland

Source: adapted from Ewing, 1991:75

same class in existing residential areas do not necessarily take the same form because they were not built to the same design standards; nor are the current planning standards necessarily enforced at the time of development.

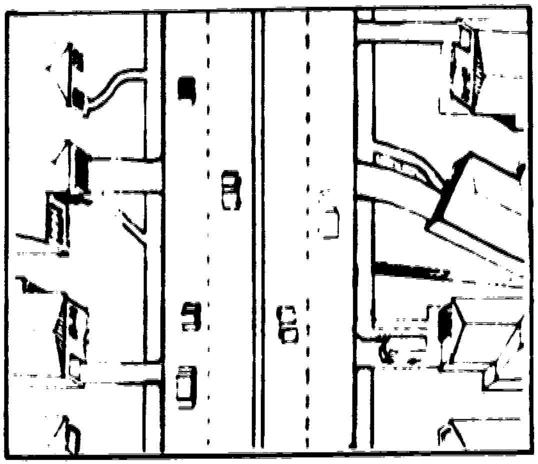
As a particular class of residential street, arterials need special consideration because of their high frequencies of pedestrian accidents, as indicated in Section 2.2.3. In residential areas, arterial streets can take three main forms, each of which has distinctive implications for pedestrian safety. These forms are illustrated in Figure 2.6:

(1) arterial streets with dwellings directly fronting on them, with narrow sidewalks immediately abutting vehicle lanes, and with unrestricted pedestrian access onto them (poorly insulated);

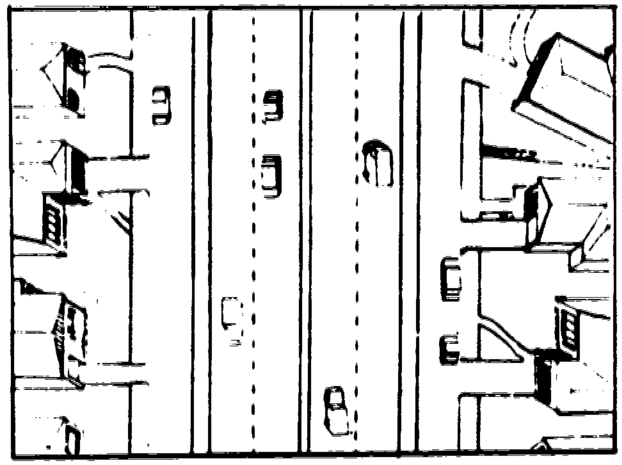
(2) arterial streets with parallel access streets (commonly called service roads), with sidewalks and abutting dwellings set back from the through street, and with reduced pedestrian access (partially insulated);

(3) arterial streets with a reverse frontage for the abutting houses, and fences or berms and screen planting in a non-access reservation along the rear property line, and with strictly limited pedestrian access (highly insulated).

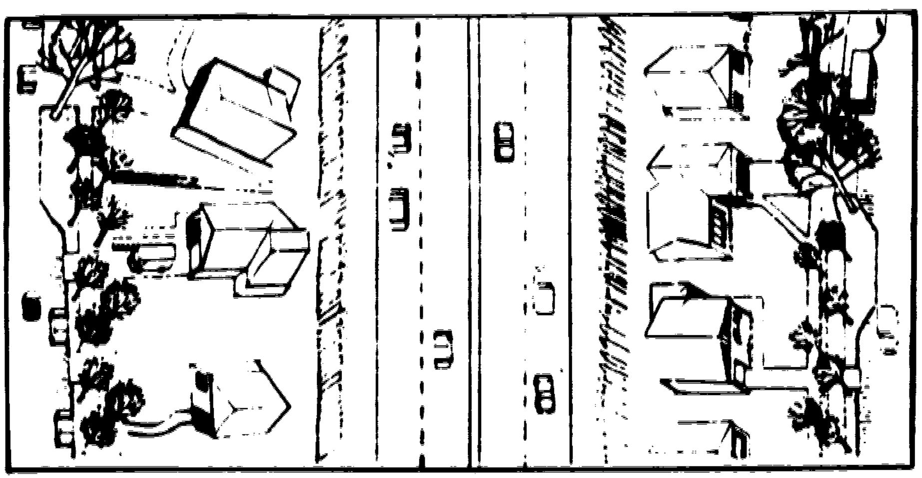
Theoretically, the first type is the least safe, because pedestrians have free access to the roadway and jaywalking is most likely to occur. The second type is an improvement over the first, since the service roads at least provide buffers



arterial street with direct frontage



arterial street with service road



arterial street with reversed frontage

Figure 2.6 Three distinctive forms of arterial streets in residential areas

for pedestrians walking on the sidewalks; they also reduce the opportunities for jaywalking. The third type, which is most preferred by planners today, should be the safest because pedestrian access to the arterial streets is restricted to a few controlled intersections and jaywalking at mid-block locations is prevented.

When streets of various classes are laid to form a network, especially a curvilinear network, there are alternative ways for them to connect with one another. This results in different types of intersections. Four main ones can be distinguished:

(1) cross-intersection (4-leg)

(2) T-intersection (3-leg)

(3) acute-intersection (3- or 4-leg)

(4) traffic circle (also called rotary intersection)

Figure 2.7 illustrates the potential pedestrian-vehicle conflict points for each of these types. In order to isolate the effectiveness of the basic design features, all forms of intersections are assumed to be uncontrolled, allowing pedestrians and vehicles to compete simultaneously for a particular space domain.

The most complex arrangement occurs at cross-intersections, where there are as many as eight pedestrian-vehicle conflict points. To make the situation worse, at four of these points pedestrians may face vehicles from three different directions: going straight ahead, making a right turn, and

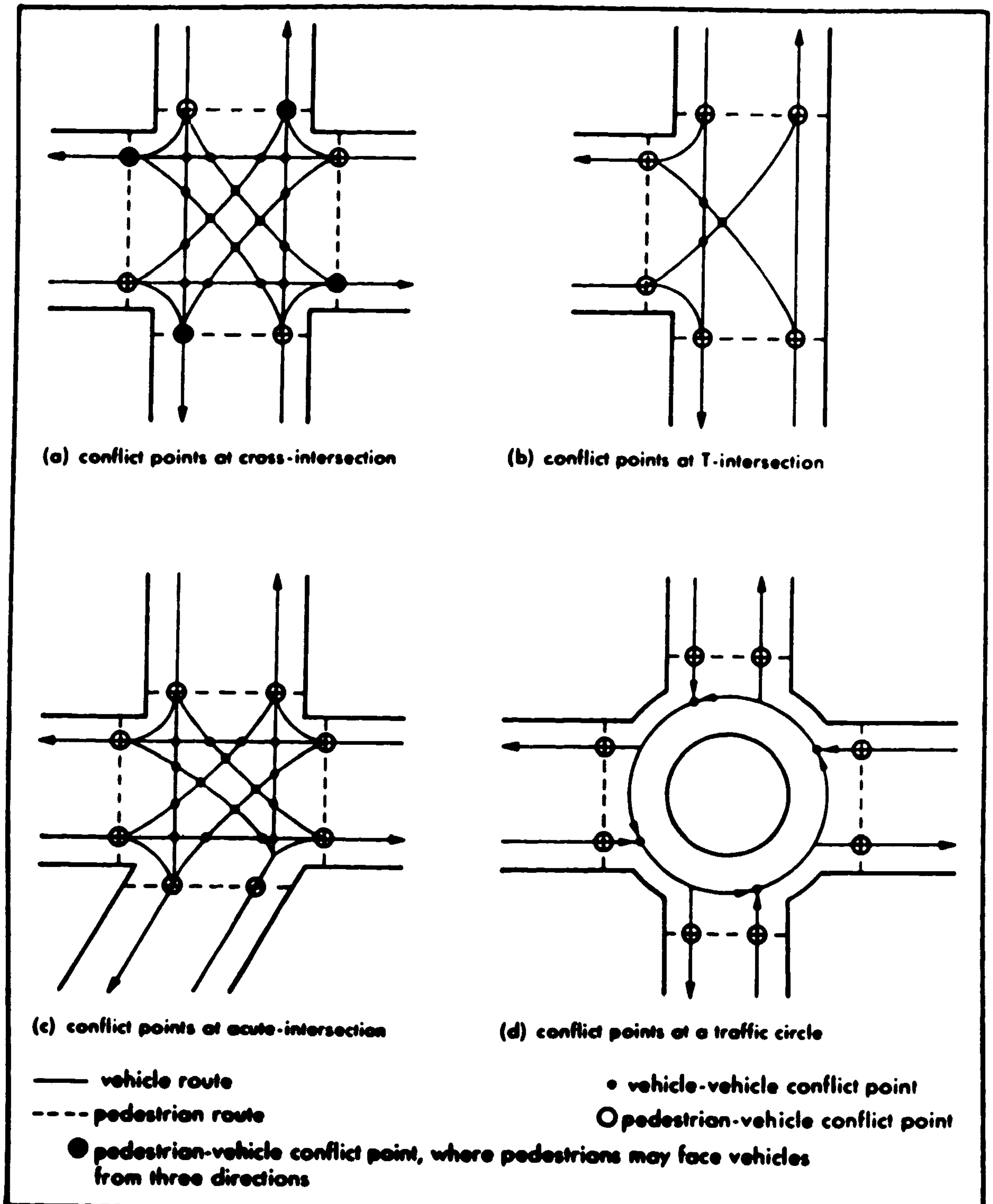


Figure 2.7 Theoretical pedestrian-vehicle conflict patterns for different forms of intersections

making a left turn. On four-lane streets, the number of pedestrian-vehicle conflict points is doubled. In addition, a cross-intersection has sixteen vehicle-vehicle conflict points. This causes drivers' attention to be highly divided, which increases the likelihood of driver errors.

At T-intersections, the number of pedestrian-vehicle conflict points is reduced to six. More importantly, pedestrians at any conflict point face vehicles from a maximum of two directions. Besides, vehicle-vehicle conflict points are reduced to three, so that drivers' attention is less divided.

The numbers of conflict points at acute-intersections are the same as those at cross-intersections or T-intersections, depending on whether they have four or three legs. The salient problem of acute-intersections is that the acute angle may block the view of both drivers and pedestrians, thus increasing the accident hazard. For this reason, acute intersections are rarely built today. It is now a principle of street design that intersecting streets should always meet at right angles.

Traffic circles are much less common than other forms of intersections in residential areas, but they are sometimes used on arterial streets forming neighbourhood boundaries, usually at the junction of two arterials. This type of intersection favours a heavy and fast flow of vehicles. If circles are located in residential areas, and especially if they are close to local service facilities, they may carry special hazards for pedestrians, though they have no more conflict points than a cross-intersection. For example, any driver who has experience of going through a traffic circle would agree that it is necessary to be aggressive to enter the circle at rush hours. Most vehicles enter and leave traffic circles at relatively high speed. Often, too, drivers are paying so much attention to the vehicles on their left that they fail to observe pedestrians on their right, even when they are attempting to cross at designated crossings.

Obviously, T-intersections should be the safest type of intersection for pedestrians because they have the lowest potential for pedestrian-vehicle conflicts. Above all, they should be safer than cross-intersections as urban planners and engineers have long recognized, beginning with the eminent Austrian planner, Camillo Sitte, more than one hundred years ago (Sitte, 1965:93-95). Cross-intersections are still widely applied, however, especially on arterial streets, because of their efficiency in channelling straight-through traffic and alleviating traffic delay. Acute intersections, on the other hand, have generally been avoided by planners, unless necessitated by the local terrain. Traffic circles, the least friendly type of intersection for pedestrians, are now out of favour in North America, even on arterial streets (American Society of Civil Engineers, 1990).

2.3.1.3. Block Pattern

In residential areas, a block is a piece of land surrounded by streets. Residential blocks can take the following general forms: (1) conventional block, (2) cluster block and (3) superblock (Figure 2.8).

Conventional blocks are subdivided into lots generally backing onto one another and fronting on streets. A backlane running the length of the street ordinarily bisects each block to provide the right-of-way for access to a rear door and a rear garage. The openings of the backlanes create extra "intersections" on residential streets. Conventional blocks are further differentiated as regular (i.e. rectangular) or irregular. The former are always associated with grid street networks and usually result in cross-intersections; whereas the latter are associated with curvilinear street networks and a higher frequency of T-intersections. Irregular blocks are also larger on average than rectangular blocks.

Cluster blocks are laneless subdivisions, with houses clustered around culs-de-sac and short-loop streets. They are irregular in shape but tend to be larger than irregular conventional blocks, though not as large as superblocks. These are the largest of all, combining houses, open spaces, playgrounds and even schools into single blocks, with internal pedestrian paths to link them together. In addition, in the true superblock form, houses are oriented to face the interior park or walkways and the culs-de-sac are for vehicle access only, whereas houses in cluster blocks have a more conventional orientation, facing the street or cul-de-sac where

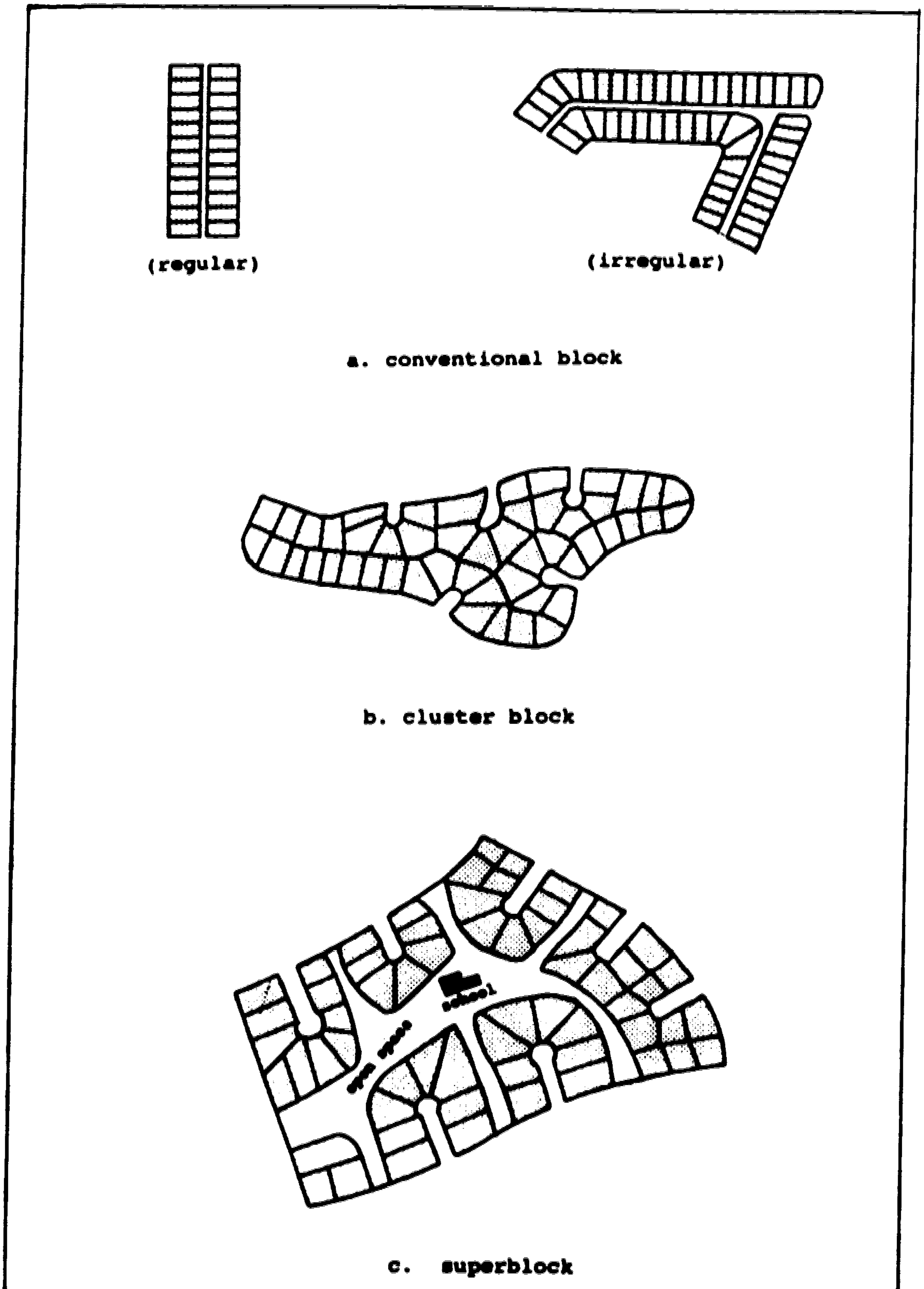


Figure 2.8 Three general forms of residential block

pedestrian traffic is also concentrated.

Generally, the more blocks a residential area is subdivided into, the more streets and intersections there are, and the higher the potential for pedestrian-vehicle conflict. As part of the development of environmental solutions to pedestrian safety, planners first shifted from regular to irregular conventional blocks with the adoption of curvilinear street hierarchies, which resulted in a corresponding reduction in street area and the number of intersections, especially cross-intersections. Then, they shifted preference again from irregular conventional blocks to cluster blocks and superblocks. This led to a further reduction in street area and the number of formal intersections, as well as eliminating the openings of backlanes on residential streets and increasing the visibility of vehicles entering and leaving front-drive garages. In addition, superblocks greatly reduce the need for inter-block pedestrian trips between homes and local service facilities. Indeed, the superblock concept was developed in the expectation that it would be superior to all other types of blocks for ensuring pedestrian safety in residential areas (Stein, 1957).

2.3.1.4. Form of Pedestrian Circulation Network

Three general approaches have been taken to the provision of pedestrian facilities in residential areas. These are referred to as integration, accommodation and separation.

(1) Integration

The integration approach is a very old practice for the treatment of pedestrians, but its modern technical term is "shared surface residential roads" (Jenks, 1986); that is, pedestrians share the street surface with other means of transportation. That was the historical pattern, but with the increasing use of automobiles, streets carrying significant vehicular volumes were no longer safe for pedestrians. Today, major streets such as arterials and collectors would never be designed on the integration principle, though it is still applied on certain access streets in low-density areas, where traffic volume is low and through traffic is unlikely or impossible. As explained in a recent technical manual (American Society of Civil Engineers, 1990:58), "On low-traffic streets such as culs-de-sac, the street itself often fulfils these functions [of serving as a meeting place for neighbours and a play area for children]".

In Europe, even more than in North America, integration has experienced something of a revival in recent years. This is illustrated by the Woonerf model developed by Dutch planners, which allows all kinds of traffic on the same street. Pedestrians are preeminent, though, and various design measures are applied to lower the speed of vehicles to the pedestrians' level (see Figure 2.9). Obviously, Woonerves are appropriate only to access streets, not to collectors or arterials, since the desired flow of traffic would be impeded

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Figure 2.9 A sketch of Woonerf, showing design features to reduce traffic speed and to provide pedestrian amenities

Source: Poulton, 1982

by the "Woonerf furniture". There is no evidence that the integration approach is ever used for planning a complete neighbourhood network.

(2) Accommodation

According to Untermann (1984), accommodation means finding room for pedestrians within the framework of public streets. Characteristically, this means that pedestrians are "accommodated" on sidewalks along residential streets. Sidewalks are the most common form of pedestrian facilities in North American cities. In older residential areas, they tend to be narrow and either abut driving lanes or are separated from them by narrow boulevards. In new areas, however, and especially on collector and arterial streets, they are commonly set back from driving lanes with planting strips as buffers so that children walking and playing enjoy increased safety from street traffic, and the danger of collision between pedestrians and out-of-control vehicles is minimized (see Figure 2.10).

Typically, sidewalks are linked to form a pedestrian circulation network by at-grade crosswalks supported by various traffic control devices (mainly traffic lights and signs). According to Ewing (1991), many planners and developers consider this approach to be adequate to meet the needs of pedestrians in residential areas. In his own survey of 58 new communities in the United States, Ewing found that most of them favoured meandering sidewalks which generally followed

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Figure 2.10 Illustration of improved sidewalks in new residential areas

Source: Homburger, Deakin, Bosselmann, Smith and Beukers, 1989:77

the street alignments.

(3) Separation

The main feature of this approach is the provision of footpath networks running through the interiors of residential blocks and separated from streets (Figure 2.11). Separated footpaths most often go hand-in-hand with superblocks to link homes with local service facilities, but they can be incorporated into cluster-blocks as well, particularly to connect pairs of culs-de-sac or to provide local access to open space. When footpaths have to cross streets, grade-separated crosswalks in the form of tunnels or bridges are favoured in principle, though they are not often built.

Many planners have praised separation as the best means of preventing pedestrian-vehicle conflict and hence of reducing the prospect of pedestrian accidents (Stein, 1957; Noble, 1977), though this is not universally agreed. There have been three main criticisms (Untermann, 1984; Tolley, 1989; Ewing, 1991). The first is that separation costs more, for both construction and maintenance. Second, vertical separation for pedestrians crossing streets is not always feasible due to its inconvenience (such as the extra effort required for climbing and descending steps). If crosswalks cannot be made safe and easy to pass, the safety gains made on internal paths are unlikely to be fully utilised. It is when crossing streets that pedestrians are mainly at risk. Third, pedestrians are less visible on separate footpaths. Ewing

Figure 2.11 A separate footpath leading to a playground in Edmonton. Also seen in the background are multi-family dwellings and other recreational facilities (i.e. a hockey rink and tennis courts), all in the same superblock.

(1991) argues that people like to see and be seen, and the kind of surveillance that occurs on a sidewalk in front of houses offers more security than a footpath network behind houses or through parks.

2.3.2 Concepts of Environmental Configuration for Residential Areas

This section reviews the major planning concepts that have influenced the form of North American residential development over the course of the 20th century. Each concept incorporates particular forms of the four design elements, the combinations of which give rise to distinctive type configurations. Since each type has its own implications for the spatial patterns of pedestrian activity and the risk of pedestrian accidents, the review will establish the basic framework that is required for a systematic evaluation of the effects of different forms of environment, unplanned as well as planned, on pedestrian safety. The review begins with a brief description of grid-pattern subdivision, representing the unplanned state of residential development. The evolution of planning principles and design concepts is then reviewed under three sub-titles: (1) the neighbourhood unit concept; (2) the Radburn and cluster-plan concepts; and (3) the principle of hierarchical organization.

2.3.2.1 Grid-Pattern Residential Subdivision

Before automobiles became widely used, cities were largely the realm of pedestrians and control of vehicular traffic was considered unimportant. At that time, the street layout most often encountered in the residential areas of North American cities was the grid with rectangular blocks, as illustrated in Figure 2.4. This type of subdivision was not designed to fit into a preset neighbourhood structure and it had no formal land use organization. Shops and commercial service outlets were often aligned along major thoroughfares in the form of a ribbon. Other facilities, such as schools, playgrounds and parks, were mostly separated from residential blocks. They were built wherever sites could be obtained, with no obvious order in relation to their service areas. Some streets had narrow sidewalks, but many had no sidewalks at all, which means that pedestrian circulation networks were not purposefully built.

Starting in the 1920s, the automobile came to the fore as an important means of urban transportation (Yeates and Garner, 1976:198). Its widespread use made the undifferentiated grid network unsafe for pedestrians. Every subdivision had a high density of streets, numerous cross-intersections and many points of access from adjoining arterials. Worst of all, the grid form meant that every residential street was a potential short-cut, drawing traffic into and through the neighbourhood and encouraging non-resident parking, especially in the vicinity of commercial ribbons. As Kostka (1954:22) remarked, "The straight lines of the grid layout lead inevitably to the use of residential streets by heavy through traffic in the hope of avoiding congestion on major arteries. Even good traffic control fails to prevent increased dangers to pedestrians crossing streets." The hazard to children was especially great, since they often had to cross many streets (including thoroughfares) to reach their schools and playgrounds. In addition, pedestrian shoppers had to cross the heavily trafficked commercial streets, as well as the frequent cross streets, to visit different shops and service outlets. The lack of convenient and safe pedestrian facilities, and a general dependence on narrow, discontinuous sidewalks without planting strips, contributed further to pedestrian-vehicle conflicts.

2.3.2.2 The Neighbourhood Unit Concept

To improve on the conditions of grid subdivisions, Clarence Perry, an American planner, proposed in the mid 1920s a new formula for the spatial organization of residential development. This was the well-known neighbourhood unit concept (Figure 2.12). Physically, according to Perry, a neighbourhood unit should be centred around an elementary school and bounded by traffic arteries or other physical barriers (such as woodlands, open areas, ravines, railways and industrial districts). Its spatial dimensions should be determined by the service area of the elementary school and the criterion that all dwellings in the neighbourhood unit

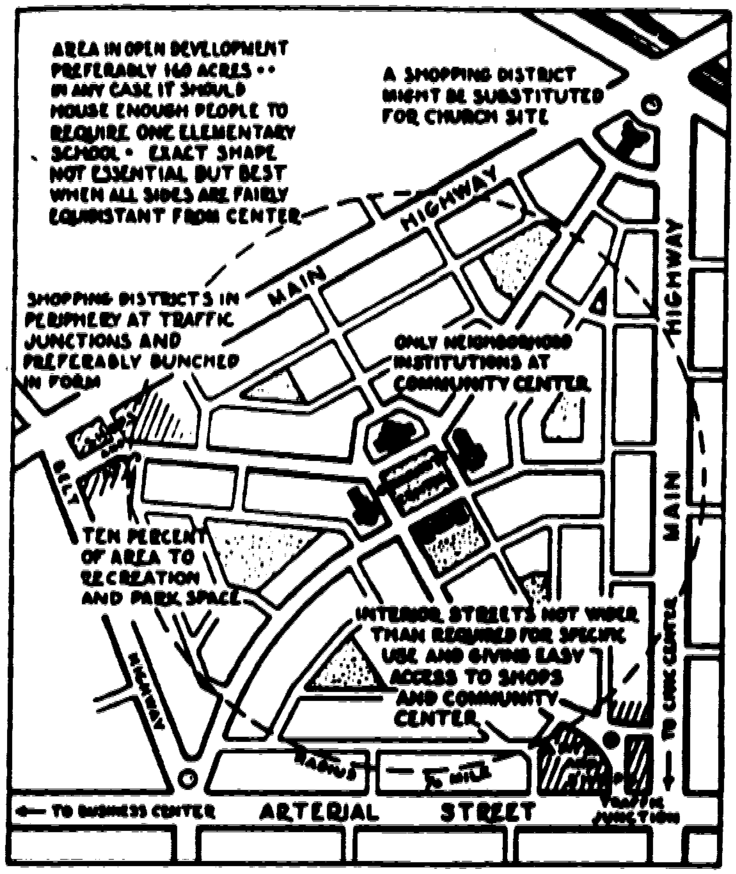

Figure 2.12 The neighbourhood unit concept

Source: Perry, 1929

ought to be within walking distance of the centrally located school. Functionally, the neighbourhood unit was proposed to be as self-contained as possible, so that residents could meet most of their daily needs within the unit where they lived. In addition to the elementary school, Perry considered that each neighbourhood unit should include such service facilities as a community meeting hall, convenience shops, and churches, and that at least 10 per cent of its total area should be in open space for play and recreation. To control through traffic and channel internal circulation, the neighbourhood streets should be laid out in curvilinear forms and with hierarchical ordering; an actual example from Calgary is shown in Figure 2.13. Dwellings would still be organized in conventional blocks, but most blocks would have an irregular shape because of the curvilinear street pattern.

Perry's neighbourhood unit has always been regarded as a major improvement over grid subdivisions from the standpoint of pedestrian safety. First of all, the whole neighbourhood was to be structured to promote safe walking. Children, in particular, would be able to walk to the neighbourhood elementary school and playgrounds without having to cross any arterial streets, as would any neighbourhood residents who wished to make use of the facilities in the community centre. Shopping facilities, also within walking distance from most houses, were proposed to be grouped in designed clusters abutting peripheral streets at neighbourhood portals, so that

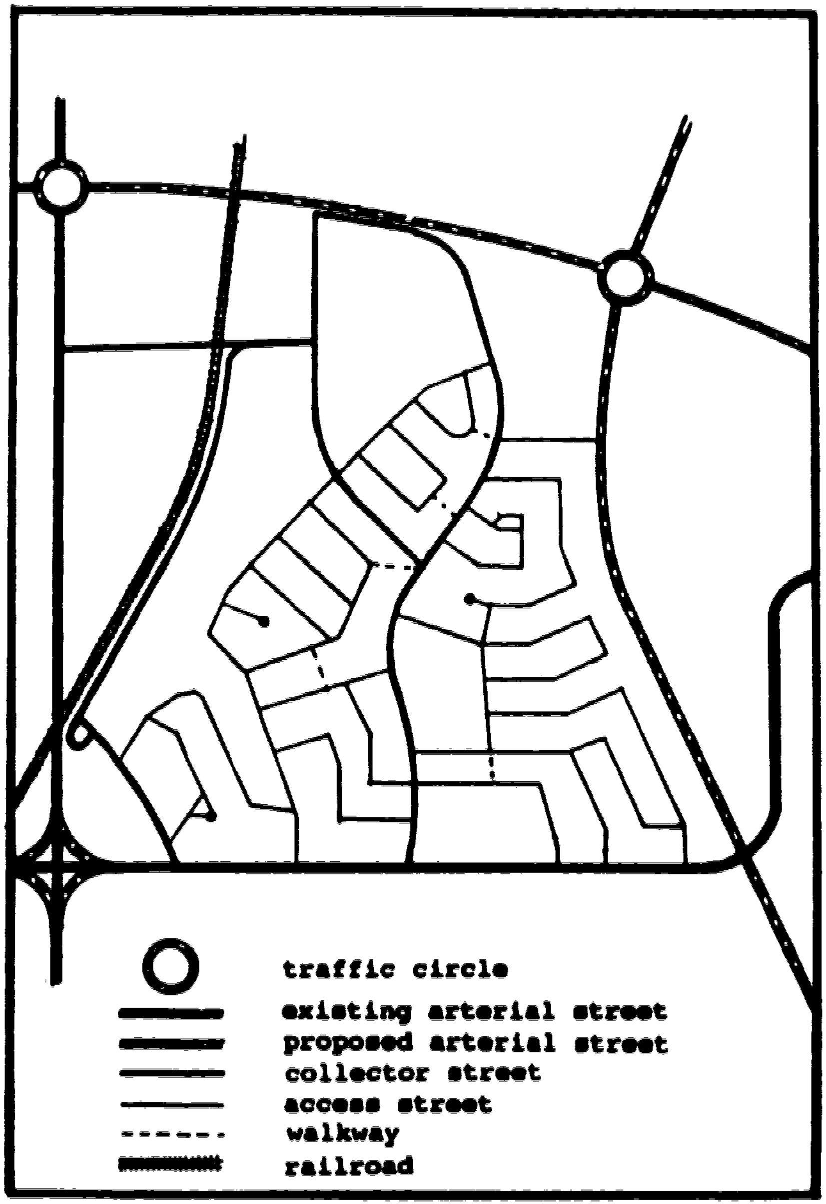

Figure 2.13 Proposed street hierarchy for a neighbourhood unit in Calgary

Source: adapted from Davis and Gordon, 1958:133

it would not be necessary for pedestrian shoppers to cross busy streets to reach a shopping centre or to visit different stores when they were there.

Second, by limiting the number of neighbourhood entrances and eliminating direct through streets, the curvilinear hierarchy ensured that only local traffic would penetrate the neighbourhood. Moreover, the definite channelling of internal traffic onto specially-designed collector roads and related design features (such as an increase in average block size, the reduced frequency of intersections, the greater use of T-intersections and the placement of houses on minor access streets) meant that the potential for conflict between pedestrians and vehicles was much less than in grid neighbourhoods. Even on collector streets it was expected that the risk to pedestrians would be minimal, because speeding was to be discouraged by the closed vistas and pedestrian crossing points would be well designed and efficiently regulated.

On the negative side, Perry did not explicitly propose any concrete forms of pedestrian facilities that would ease intra-neighbourhood pedestrian movement; nor did he propose measures to insulate peripheral houses from boundary streets. Most importantly, he conceived the neighbourhood as a largely independent unit with little functional relation with adjacent areas. The neighbourhood unit principles prescribed nothing about the spatial arrangement of those local service facilities that draw on the population of more than one neighbourhood unit, such as high schools and parochial schools. This also meant that the issue of pedestrian safety on boundary streets was given inadequate consideration, which led Blackman (1966:12) to the following assertion:

> "I hesitate to presume that a restudy would verify that limited access subdivisions [his term for the neighbourhood unit] are also safer [than grid subdivisions] for pedestrians. Furthermore, a restudy would only indicate whether children are safer walking within a limited access subdivision; it would not indicate whether children are safer walking between subdivisions. It is the between-subdivision question which is raised by proposals to alter the neighbourhood school patterns."

Nevertheless, neighbourhood unit principles were widely adopted, not just in North American cities but throughout the industrial world. It should also be pointed out that Perry's diagram was a planning concept only, not a design model. Every neighbourhood unit has to be individually designed to fit its specific context, with the result that neighbourhoods built to Perry's principles show considerable variation in their detailed forms, including land use arrangement as well as street layout. The treatment of boundary streets varies too, in the manner illustrated in Figure 2.6. Variations of these kinds have important implications for pedestrian safety, especially the safety of inter-neighbourhood pedestrian trips. They not only affect the frequency of such trips, depending on the degree to which residents must look to adjacent neighbourhoods for essential services, but they influence the effectiveness with which vehicular-pedestrian conflict can be managed in individual situations.

2.3.2.3 The Radburn Concept and Cluster Subdivision

To further enhance pedestrian safety in residential areas, Henry Wright and Clarence Stein, also American planners and Perry's contemporaries, took a highly innovative approach to the design of residential environment. This became known as the Radburn concept, after the community where it was first employed, and its important attribute was a radical revision of relations among homes, blocks, paths, streets, and open spaces. One of its main purposes was to separate pedestrians from automobile traffic as much as possible.

In terms of environmental design elements, the Radburn concept adopted the following unique features (Figure 2.14):

1. As in Perry's concept, residential areas were organized into neighbourhood units centred around an elementary school, but the neighbourhood form was quite unlike that of conventional neighbourhood units. In the Radburn model, each neighbourhood was subdivided into a small number of superblocks, in which open spaces, playgrounds and even schools and related facilities were combined with dwellings for safe and easy pedestrian access. This is where the superblock concept was formally developed in its North American application. In the original Radburn development, houses were grouped in clusters on the peripheries of superblocks and reversed to face onto the interior open spaces.

2. The internal streets at Radburn were also laid out in curvilinear forms and with hierarchical ordering, as Perry

Figure 2.14 The Radburn concept

(This figure, showing one neighbourhood of two superblocks, illustrates the major Radburn features: internal open spaces and playgrounds, separate footpaths, and dwelling clusters around culs-de-sac.)

Source: Adams, 1934:268

proposed, but access to dwellings was mostly in the form of culs-de-sac which opened directly onto collector streets. They were better described as service lanes than streets, both because of their narrow width (20 feet or less) and because they were designed to provide rear access only.

3. Separated footpaths running through the open spaces in the interiors of the superblocks formed an extensive pedestrian circulation network to connect homes with service facilities. Where these paths had to cross streets, leading from one superblock to the next, grade-separated crosswalks were provided.

The organization of neighbourhood facilities in the Radburn concept was a further improvement over Perry's neighbourhood unit. For example, playgrounds and open spaces in the interiors of residential blocks should be superior pedestrian activity spaces, especially for children engaged in play and adults walking for exercise. Other interior facilities (such as schools and community halls) also help to reduce inter-block pedestrian trips.

As to the control of traffic flows, the Radburn approach can again be regarded as superior to the normal form of neighbourhood unit. Since superblocks are much larger than conventional blocks, the density of streets and intersections and the number of neighbourhood entrances can be greatly reduced in Radburn subdivisions. In superblocks, automobiles are concentrated in the culs-de-sac where garages are located, leaving the other side of the house free from traffic. The cul-de-sac should be a particularly safe form of access street because no through traffic is possible there.

Unlike conventional sidewalks along streets (i.e. the accommodation approach), the footpaths at Radburn are incorporated into the interior open spaces, which completely separate pedestrians from vehicles. Grade-separated crossings provide further protection for pedestrians, and are especially valuable for inter-neighbourhood pedestrian trips across arterial streets.

Wright and Stein's concept was first tested with a physical form in 1928 at Radburn in the Borough of Fairlawn, New Jersey. It was then followed in the development of a number of model American new towns (Stein, 1957), and was widely used in the British new towns as well (Parsons, 1992). In general practice, however, the concept has had its widest application in multi-family housing projects, rather than in the development of entire neighbourhoods. In its low density form, developers commonly considered Radburn-style superblocks to be uneconomical, and reversed houses have never proved popular with either developers or homeowners. It was not until the Radburn model was adapted into a new form, known as the cluster subdivision or the cluster-plan neighbourhood, that it came to have widespread influence (Whyte, 1964).

Cluster subdivision was initially favoured for economic reasons, to reduce clearing and grading costs and to save on the infrastructure needed to service residential units. Cluster subdivisions retain the cluster housing patterns of the Radburn concept (i.e. houses are grouped around culs-de-sac), but have four distinctive features (National Association of Home Builders, 1976; O'Mara, 1978; Sanders, 1980). First, in areas of cluster subdivision, only the most developable land is subdivided for housing. Less developable land is preserved for natural landscape or for recreation grounds. This implies that open spaces for amenity and recreation do not necessarily form the backbones of superblocks. Second, most blocks are cluster blocks (see Figure 2.8), though one or two superblocks typically occupy the core of the neighbourhood (Figure 2.15). They tend to be modified from the Radburn model, however, in the sense that houses are not normally reversed but have a conventional orientation on their access streets, as in cluster blocks. Culs-de-sac are given a more conventional street form as well, being wider and more visible to drivers than those at Radburn. Third, the whole neighbourhood is served by a continuous collector street, which is adequate for internal traffic flow and efficient for public transit services, but offers no benefits for through traffic. With low traffic volumes, grade-separated crosswalks are not thought to be needed in the interiors of cluster-plan neighbourhoods. Finally, walkway networks take composite forms, combining the separation approach (in superblock interiors and linking culs-de-sac in cluster blocks) with the accommodation

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Figure 2.15 An American example of cluster-subdivision neighbourhood

Source: Whyte, 1964:74

approach (in cluster blocks) and perhaps the integration approach (in individual culs-de-sac).

Over the past 25 years or so, the cluster-plan concept has become the norm in residential planning and design in North American cities. In its individual applications, however, the variations in detailed neighbourhood form are almost infinite.

2.3.2.4 Adapting the Neighbourhood Unit to a Hierarchical Structure of Residential Organisation

With the rapid progress of suburbanization and the increasing demand for public services, it was realized that traditional neighbourhood units of whatever form, Perry, Radburn or cluster-plan, were too small to provide for all needs of modern suburban life. As Carver (1962:60) pointed out:

> "The population that supports one elementary school is not large enough to support the principal social and commercial services on which suburban life depends. ... A comprehensive system for residential areas must, therefore, be conceived at a scale larger than the neighbourhood, so that it can embody all the essential features of suburban living which are extra-territorial to the neighbourhood".

More recently, with changes in the demographic profile of North American cities (e.g. a declining birth rate and an aging population) and shrinking public funds, local governments have come to seek ways of providing basic services more efficiently and cost-effectively. This implies that individual neighbourhoods should no longer be treated as though they were functionally self-contained units. Some sharing of local services and facilities (even public elementary schools) has come to be seen as unavoidable (Edmonton, 1990:15), adding further impetus to the idea that neighbourhoods should be grouped into larger spatial units.

The principle of hierarchical organization of residential environments germinated in England in the late 19th century, in Ebenezer Howard's garden city concept. The garden city was originally conceived as a spatially independent and functionally self-contained town surrounded by a green belt of open farm land. The town itself was proposed to consist of several wards (equivalent to neighbourhoods) grouped around a centrally located town centre (Howard, 1945:51). This elementary concept was adopted by North American planners in the 1920s and 1930s, in the development of model American new towns. Radburn, for example, which was conceived as a detached suburb of New York, was planned to comprise three neighbourhoods organized around a subway station and the associated town centre. Unfortunately, the complete plan of Radburn was never achieved due to the failure of Stein and Wright's development company during the financial crisis of 1929, but similar logic was followed in the design of the so-called "greenbelt towns" in the 1930s (Stein, 1957).

Although the principle of hierarchical organization was originally conceived for, and tested in, the development of free-standing new towns, as North American cities extended rapidly and massively into their suburbs after World War Two, urban planners recognized that it could be applied in somewhat modified form to the organisation of suburban residential areas. This is what Carver (1962) theorized about in his book Cities in the Suburbs, by which he meant that suburban extensions should be planned as largely self-contained service units and organized with a hierarchical structure similar to that being employed in the post-war British new towns. The prototype in Canada was Don Mills in suburban Toronto, which was planned in 1952 to include four neighbourhoods clustered around a town centre (Sewell, 1977). Other Canadian cities, including Edmonton and Calgary, began to adopt this approach in the 1960s (Harasym and Smith, 1975; Graden, 1979).

In general, the main objective of hierarchical organization is to enhance functional relations among spatially adjacent neighbourhoods and to make a broader array of services accessible to a heterogeneous population. A fundamental requirement of hierarchical planning is to strike a balance between optimum choice in local services and easy access to these facilities (Hoppenfeld, 1967).

In terms of physical form, a hierarchy can be structured with either a two-level order or a three-level order, depending on the size of the development area (Smith and Moore, 1993). In a two-level hierarchy, the order is neighbourhood-community; in a three-level hierarchy, it is neighbourhood-community-suburban town, though there are no fixed titles for the higher order units. For instance, a community is called a village in the new towns of Columbia in Maryland and Reston in Virginia; the suburban town level is called a district in Edmonton, but a sector in Calgary.

Figure 2.16 illustrates the concept of a 3-level hierarchy. Neighbourhoods are still the basic development "cells" or building blocks, but they are no longer regarded as independent units, and their boundaries and physical separation are not always as clear-cut as they once were. Individual neighbourhoods, which are usually configured on the cluster-plan model, continue to be organized around an elementary school combined with a park site, so that young children can have easy access to school and play facilities on foot. Several adjacent neighbourhoods then form a community, which is focused on shopping, secondary education facilities and parochial schools, as well as on more specialized recreational and public service facilities, such as swimming pools and branch libraries. At the next level, groups of communities are organized into a district or suburban town around a "town centre" which, as described by Carver (1962: 92-96), should include four distinct types of functions, all in a purposefully designed pedestrian environment:

(1) moderately specialized commercial facilities in the form of a market square or mall (i.e. a district or regional shopping centre)

(2) a cluster of cultural and institutional facilities,

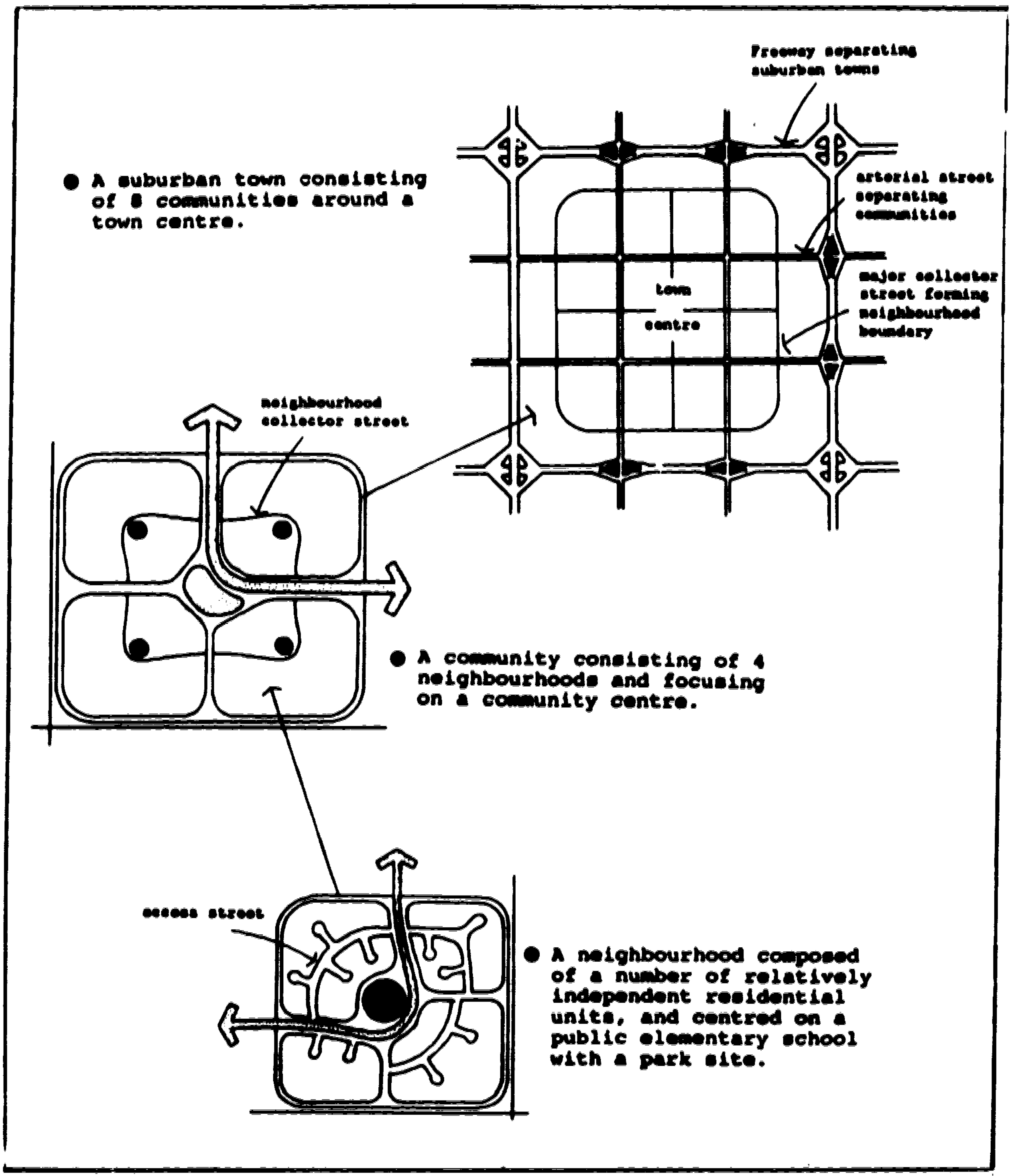

Figure 2.16 A concept of a 3-level hierarchy

Source: adapted from Edmonton, 1971 and from Calgary, 1973

including senior high schools, a theatre auditorium, a library, and a hospital

(3) office buildings housing civic functions and professional services

(4) a large park for recreation and amenity landscape.

These functions in a town centre all require higher population thresholds (or catchment areas) than lower-level services and facilities, but none of them should be broadly-oriented to attract outside traffic. Grouping various services and facilities into spatial clusters not only reduces walking distances from one facility to another, but also favours pedestrianisation of the town centres.

In order that the maximum number of residents can have easy access to the most frequently-visited local service facilities, multi-family dwellings and senior citizens residences are normally located near the community and town centres, where diversified services and facilities are clustered. Detached houses mostly take peripheral locations in the community or town, since they tend to be occupied by relatively affluent families with private transportation means. They are also more likely to have their own outdoor spaces in the form of private yards and gardens.

Associated with the hierarchical structure of land use organisation is a distinctive hierarchy of streets (Figure 2.16), whose purpose is to facilitate internal vehicular movement within communities and neighbourhoods while channelling necessary through traffic in a safe and efficient manner. At the top of the internal hierarchy is a network of arterial streets, which bound communities and effectively direct traffic outside the "town" onto freeways or expressways which also form district boundaries. No arterial streets should directly serve residences, even with service roads. Dwellings are insulated from these streets by wide buffer zones and are reversed to face into their neighbourhoods (see Figure 2.6). Arterial streets are to be designed with special care for pedestrian safety. For example, no pedestrian generators, such as shops, schools and playgrounds, should be located immediately along the arterial streets; neighbourhood exits should be avoided on such streets as much as possible; and safe pedestrian crossings must be provided at those few locations where pedestrian walkways intersect the arterials. The second level of the street hierarchy is usually a network of major collector streets (alternatively called minor arterials in some publications), which channel community traffic to and from arterial streets, and tie community centres with the town centre. At the third level are ring-shaped collector streets which connect all the neighbourhoods of a community and lead local traffic to the major collectors on neighbourhood boundaries. Collector streets are also major bus routes penetrating neighbourhoods and linking multi-family dwellings, which are mostly located on bus routes, to the community and town centres. The lowest level of the street hierarchy comprises access streets in the form of either short loops or culs-de-sac.

To deal with the inter-neighbourhood pedestrian trips generated by the sharing of local facilities, hierarchical planning calls for extensive pedestrian circulation networks, in the form of either separate footpaths or sidewalks. Thus, pedestrian circulation networks at the neighbourhood level are connected to form a community-wide network; and the community networks, in turn, are connected into a town-wide system, focusing on the town centre. It should also be evident from this description that the concept of environmental configuration applies at all three areal scales. Moreover, individual communities and suburban towns are just as likely to vary in their detailed configurations as individual neighbourhoods are.

2.4 Implications for the Research Design

Residential areas are important pedestrian activity spaces, yet they are required to accommodate a great deal of vehicular traffic as well. There is always some potential for conflict between pedestrians and vehicles as a consequence, with children and elderly people being particularly vulnerable to the accidents that then result. Among the various factors that may contribute to this outcome (including human behaviour and weather-related road conditions), the configuration of the built environment plays an important role because pedestrian activity patterns and potential conflict should, in theory, be influenced by the spatial arrangement of local service facilities in relation to various types of dwellings and transportation facilities. This also implies that it should be possible to minimize pedestrian-vehicle conflict through deliberate manipulation of the built environment, hence reducing the occurrence of accidents.

For a long time, planners have been making conscious efforts to improve pedestrian safety through environmental solutions. Planning concepts have also changed over time, but they have always been based on the same 4 critical design elements: viz. land use pattern, street pattern, block pattern, and pedestrian circulation network. Each of these elements can take different forms, and each form has distinct implications for pedestrian safety. In fact, many of the alternative forms of individual design elements represent specific environmental solutions that planners have incorporated into their residential designs with the aim of enhancing pedestrian safety. For example, they devised planning principles according to which dwellings and local service facilities could be organized so as to require pedestrian users to cross a minimum number of arterial streets to reach the facilities from their homes; they adopted hierarchical street networks which made extensive use of such features as loop streets, culs-de-sac and T-intersections; they invented superblocks which incorporated dwellings and local service facilities into the same blocks and also resulted in low street density, low intersection density and limited neighbourhood entry points; and they applied footpath networks to separate pedestrians from vehicles.

However, since the design elements go hand-in-hand in the configuration of complete residential environments, individual environmental solutions are always implemented in combinations. This implies that the overall effectiveness of combinations is more important than that of the individual elements separately, because after all, residents interact with the environment as a whole, not just its components. In terms of alternative forms of environmental configuration, the following normative design concepts have been formulated at different times to guide residential development in North American cities: grid-pattern subdivision; the neighbourhood unit concept; the Radburn concept; the cluster-plan concept; and the concept of hierarchical organization. In theory, neighbourhoods of all types can be grouped into larger units with hierarchical structures, though in practice cluster-plan neighbourhoods are usually employed. The key point, however, is that individual neighbourhoods are not configured in isolation, as though they were independent units. Rather, each is treated as a component of a larger unit deliberately organized into a hierarchical structure to share local service facilities, especially facilities that need the population of more than one neighbourhood to sustain them.

These general concepts of residential form and organization give rise to different types of neighbourhoods, which represent distinctive forms of residential environment, both planned and unplanned. Yet, although neighbourhoods of the same type follow the same general planning and design principles, they do not have identical configurations. As described in Section 2.3.3, for example, since neighbourhoods built to Perry's principles were individually designed to fit their specific contexts, they show considerable variety in their detailed forms. For that matter, Perry's planning principles are essential to the Radburn and cluster-plan concepts as well; they differ in their physical forms because of radically different treatments of street patterns, block patterns and pedestrian networks. Generally speaking, all design elements vary among neighbourhoods of the same type, but land use patterns tend to vary most, without departing from type. This mainly reflects the fact that not all neighbourhoods need have the same local service facilities. Since certain types of facilities (such as public high schools, parochial schools and district shopping centres) serve the population of more than one neighbourhood, they can be hosted by some neighbourhoods only, not by all of them. These within-type variations may have a significant influence on vehicular and pedestrian flow patterns at a local scale, and therefore affect the overall safety of the particular combinations of environmental solutions prescribed in the different design concepts.

From the review presented in this chapter, 3 broad questions emerge about the effectiveness of environmental configuration from the standpoint of pedestrian safety:

(1) Are certain types of residential environments really safer than others, as believed by the planners who deliberately configured them in accordance with particular design concepts? And to the extent that they are safer in general, are they also safer for different segments of the population, especially for children and elderly people who are most vulnerable to pedestrian accidents?

(2) If certain types of residential environments are indeed safer than others, is it because of the particular forms of the individual design elements that were consciously incorporated into their design? That is, is it because of the specific environmental solutions that are characteristic of the type configurations?

(3) Are there significant differences in pedestrian safety among neighbourhoods of the same general types? If there are, can these differences be attributed to variations in their local environmental configurations, and so cast further light on the safety effects of certain environmental design concepts?

These questions cannot be satisfactorily answered from the existing research literature. First, of the studies that did associate pedestrian accidents with features of the built environment, all were focused on limited aspects of street design; none has been found to systematically investigate the effects of other environmental solutions or the overall effectiveness of different environmental configurations. Second, most studies of pedestrian accidents were done in European countries, and the known characteristics of pedestrian accidents and their planning implications were mainly generalized from the European studies. Their findings cannot readily be used to assess the environmental solutions that were largely developed and implemented in the North American context because of the significant differences between the two continents in their urban forms and travel patterns. For example, residential densities are generally lower in North American cities, whereas rates of automobile ownership are higher.

In light of these evident gaps in the research record, the present problem was conceived to focus on 3 inquiries which also constitute the particular objectives of the thesis.

The first objective is to evaluate, in the North American context, using Edmonton as the case example, the relative safety of the basic forms of residential environment as they have been distinguished in Section 2.3. This inquiry intends to reveal (1) if planned residential environments in general are safer for pedestrians than unplanned environments, as planners have long believed, and (2) which form of environment is the safest in general and should therefore continue to be followed as the model for future residential planning. The evaluation will use neighbourhoods as the basic analytical units, and grid neighbourhoods as the control against which the safety of planned neighbourhoods of all types are compared. The evaluation will be conducted for different age groups as well as for total neighbourhood population, to find out if "safer" residential environments benefit all age groups, and especially school-aged children and elderly people.

While the comparison of the different types of neighbourhoods is a necessary first step, it does not in itself establish that differences in their pedestrian safety can be attributed to differences in the forms of those particular features of the built environment that planners have been chiefly concerned to manipulate. The second objective, then, is to assess the relative effectiveness of the alternative forms of individual design elements by analysing their associations with the incidence of pedestrian accidents. This examination, as an extension of the first inquiry, serves to explain whether some forms of residential environments are safer than others because of the particular environmental solutions, represented by preferred forms of individual design elements, that were incorporated into their designs.

The third objective is to determine whether neighbourhoods of the same type vary in their degrees of pedestrian safety, and, if they do, to relate the variations to differences in local environmental configuration. That is, to determine the safety effects of differences in configuration at the scale of the individual neighbourhood, and hence to come to a more complete understanding of the effectiveness of the various environmental solutions that planners have devised.

To fulfil the above research objectives, using Edmonton as a case study, the following procedure is pertinent:

(1) Review Edmonton's residential planning and development history to identify the different forms of residential environments that are represented there. This is needed for two reasons: to determine if Edmonton is an appropriate setting for a case study given the array of environmental solutions that is theoretically available; and to permit the development of an Edmonton typology that will provide the substantive framework for the evaluation of the safety effects of different environmental configurations.

(2) Based on the Edmonton review, formulate research hypotheses about the safety effects of different types of residential environments and the relative effectiveness of different forms of individual design elements. The hypotheses must relate to the particular Edmonton context to make sure that they are testable in the case study and that local data are available to allow them to be tested.

(3) Before the hypotheses are tested, extract some general characteristics of pedestrian accidents in Edmonton

from the local accident records to establish the validity of the research problem as hypothesized. Four points are of greatest pertinence. To determine (1) if pedestrian accidents are a salient problem in Edmonton's residential areas and therefore justify the study of residential planning and design for pedestrian safety; (2) if children and the elderly are more vulnerable to accidents than other age groups in Edmonton and so should receive particular attention in the case study; (3) if winter-related road conditions are a significant factor in pedestrian accidents in Edmonton, thus reducing the effect of the built environment and undermining the relationships postulated in the hypotheses; and (4) if traffic control devices (or regulatory measures) are sufficient on their own to minimize the risk of pedestrian accidents and so reduce the need for environmental solutions.

(4) Test the research hypotheses by analysing three general kinds of data: pedestrian accident data, environmental data and population data. More particularly, the research problem requires local accident data to be analyzed in relation to types of neighbourhoods, alternative forms of individual design elements, and the distribution of neighbourhood population into pertinent age groups. Taken together, these analyses will constitute the substantive core of the thesis and will provide detailed information that can then be interpreted in light of the research questions and objectives.

In sum, the three inquiries on which the thesis will focus complement one another to form a comprehensive and systematic evaluation of the various planning principles and resultant environmental solutions that have been employed in North American cities in the past 70 years or so, to cope with the problem of pedestrian safety in residential areas.

CHAPTER 3

A RETROSPECTIVE VIEW OF RESIDENTIAL PLANNING AND DEVELOPMENT IN EDMONTON: SETTING THE LOCAL CONTEXT FOR THE RESEARCH PROBLEM

Chapter 2 has laid down a conceptual framework for the thesis research. The main purpose of Chapter 3, which reviews in detail how the various forms of the design elements have been applied in Edmonton, and the types of neighbourhoods that have been created, is to construct the local classification scheme that is required for a comparative evaluation of the safety effects of different kinds of residential environments. In the process, the review will demonstrate why Edmonton is an appropriate setting for a case study in the North American context.

For thesis purposes, the history of residential development in Edmonton can be split into four periods according to the major planning approaches that Edmonton followed and the distinctive forms of built environments that were created as a result. These periods are: 1) unplanned residential development prior to 1950; 2) development planned on conventional neighbourhood unit principles in the 1950s and early 1960s; 3) hierarchical organization of residential areas between the mid 1960s and the late 1970s, when separation was the primary approach to the provision of pedestrian facilities; and 4) continuation of hierarchical organization in the late 1970s and 1980s, but with a return to the "accommodation" of pedestrians. In relation to the theoretical developments in ential planning and design described in Chapter 2, the t period corresponded to grid-pattern subdivision; the second period witnessed the wide application of Perry's neighbourhood unit concept, though with modifications in some circumstances; and the third and fourth reflected the adoption of the principle of hierarchical organization combined with the strong influences of the Radburn and cluster-plan concepts. The characteristics of each period will be reviewed in turn.

3.1 Unplanned Residential Development, Prior to 1950

Alberta adopted its first planning act in 1912, but that initial legislation had no practical effect on Edmonton's physical form (Smith, 1979). Then, in 1929, the Alberta planning system was extensively reformed, and substantial new powers were extended to municipal governments (Smith, 1986). Following this, Edmonton appointed a Town Planning Commission to advise City Council on land allocations for streets, parks and public services, and to regulate development by means of a zoning bylaw, which the Commission drafted. The bylaw was adopted by Council and approved by the Provincial Minister of Public Works in 1933. The Commission also prepared a major street plan, though it was never officially adopted. In other respects, as well, planning was ineffective in this period (Dale, 1969). Above all, no comprehensive plans were conceived, either for the city as a whole or for residential sectors, and no form of subdivision control was employed.

With respect to physical form, the initial agricultural settlement in Edmonton was organized in 1883 into long, narrow river lots, providing each homestead with a portion of river front. This earliest subdivision was in line with the policy of the Government of Canada, which stated that settlements bordering any river or lake or other body of water should be subdivided into lots of a certain frontage and depth (Dale, 1969). Edmonton's river lots were later subdivided on a grid for development purposes by surveyors working for land speculators and real estate agencies (Gilpin, 1986). As the city grew into the areas covered by the standard square-mile sections of the Dominion Land Survey, the pattern of grid subdivision extended far beyond the original river lots (Figure 3.1). The creation of new subdivisions reached a peak during the land boom of 1910-1912 (Smith, 1990). Except for those subdivisions within the central part of the city, however, most land remained vacant until after the Second World War. Before 1950, the morphological development of Edmonton was mainly based on this grid system, superimposed on the old river lots. Some radial arterial roads deviated from the standard grid but only because they followed old trails or the lines of original settlement.

The residential areas developed prior to 1950 are indicated in Figure 3.2. They were mainly around the central downtown area and in the old towns of Jasper Place, Beverly,

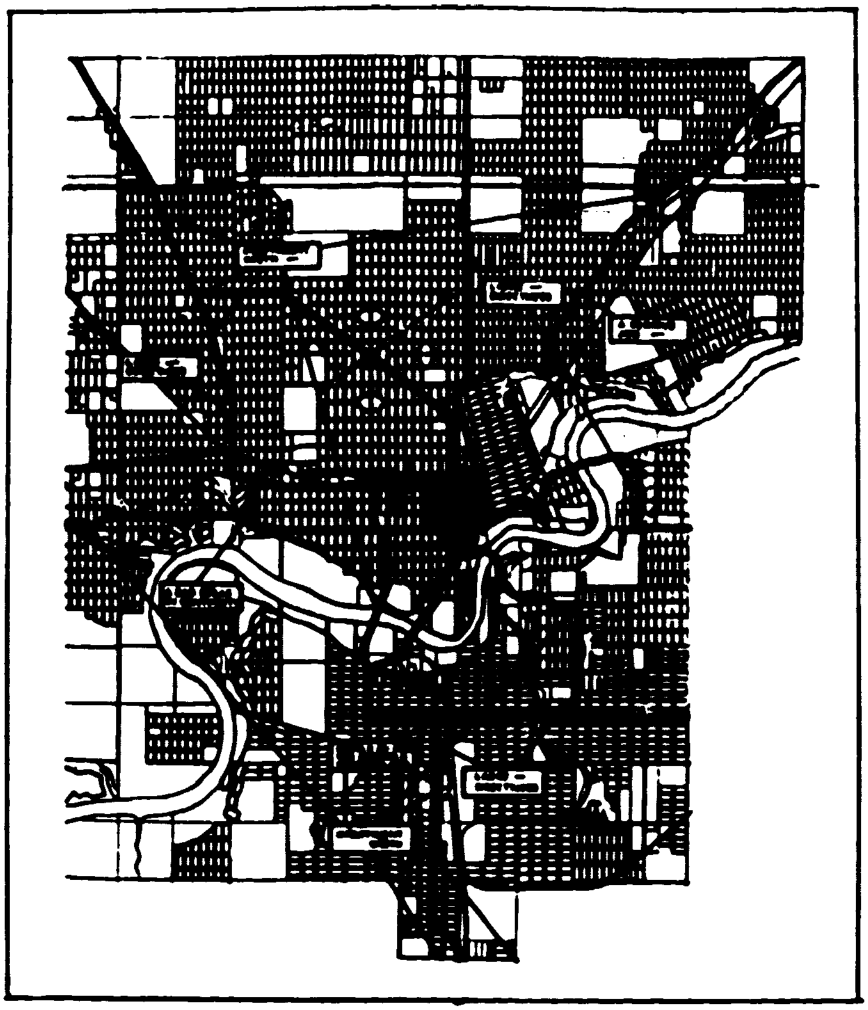

Figure 3.1 Grid subdivision in Edmonton (Edmonton's street network in 1930)

Source: Edmonton Planning Department, 1966:13

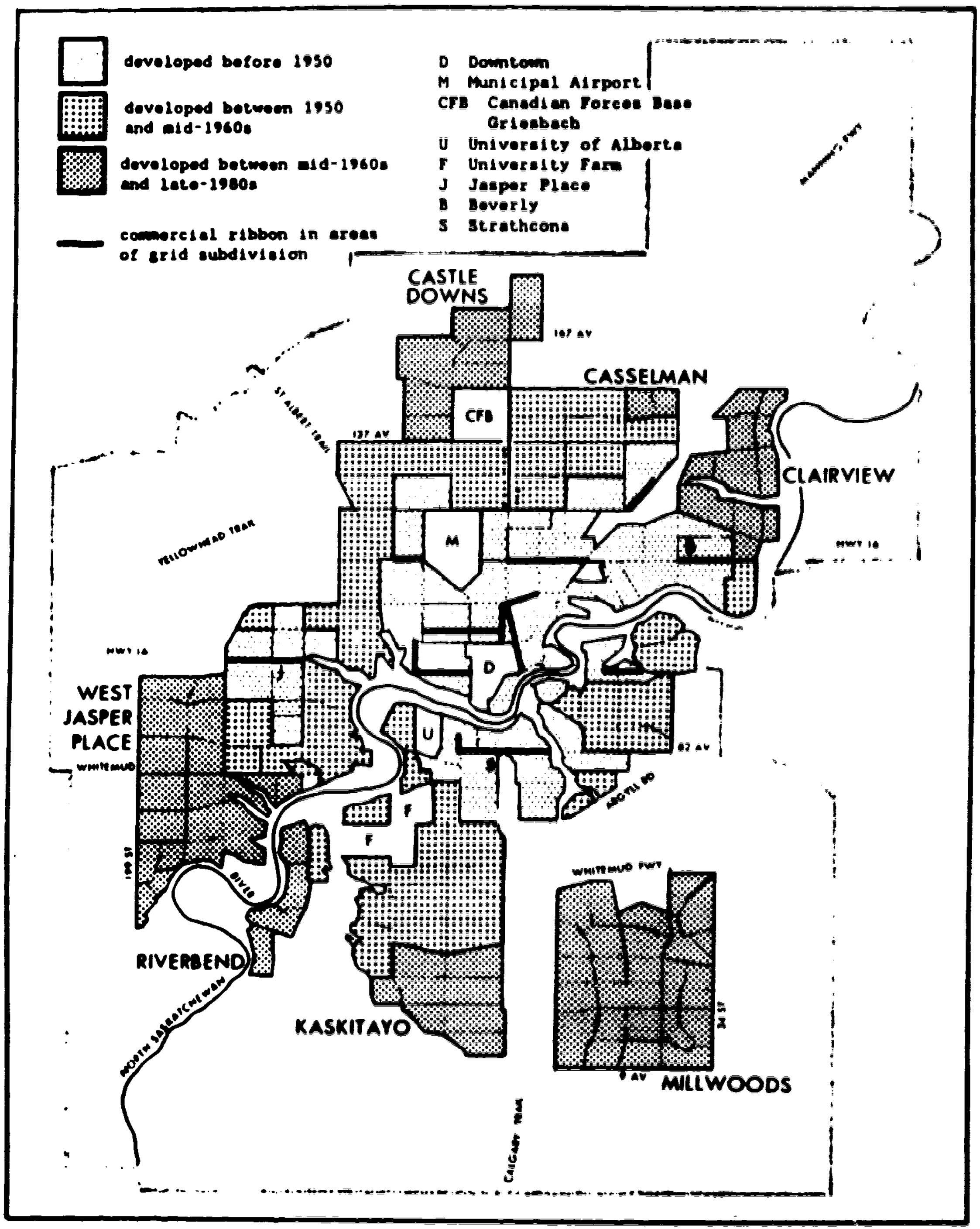

Figure 3.2 Residential areas in Edmonton by period of development

and Strathcona. Although they were later classified into smaller units referred to as "old neighbourhoods" for urban renewal purposes (Edmonton, 1977a), they followed none of the principles proposed by Perry in his neighbourhood unit concept.

Typically, as illustrated in Figure 3.3, Edmonton's grid neighbourhoods are distinguished by straight streets of standard width (normally 66 feet), which create a regular pattern of small rectangular blocks and closely-spaced intersections. Block dimensions vary but are commonly about 500 feet by 300 feet. Dwellings front on streets of all kinds, including thoroughfares, and narrow sidewalks immediately abut vehicle lanes within the street right-of-way. Parks, playgrounds and schools are mostly separated from residential blocks and are located wherever sites could be obtained. There are scattered corner stores selling groceries, but most retailing outlets and services are aligned along major thoroughfares and former streetcar routes to form commercial strips (see Figure 3.2 for the major commercial strips in the grid areas in Edmonton and Figure 3.3 for a particular example on Stony Plain Road). As Noel Dant (1954:31), Edmonton's first town planner, described, the general form of Edmonton's residential areas in 1949 was little different from that of any other Canadian or American city of like size: "endless streets of gridiron-planned housing, with the odd intersection of so-called main highways festooned with local businesses at

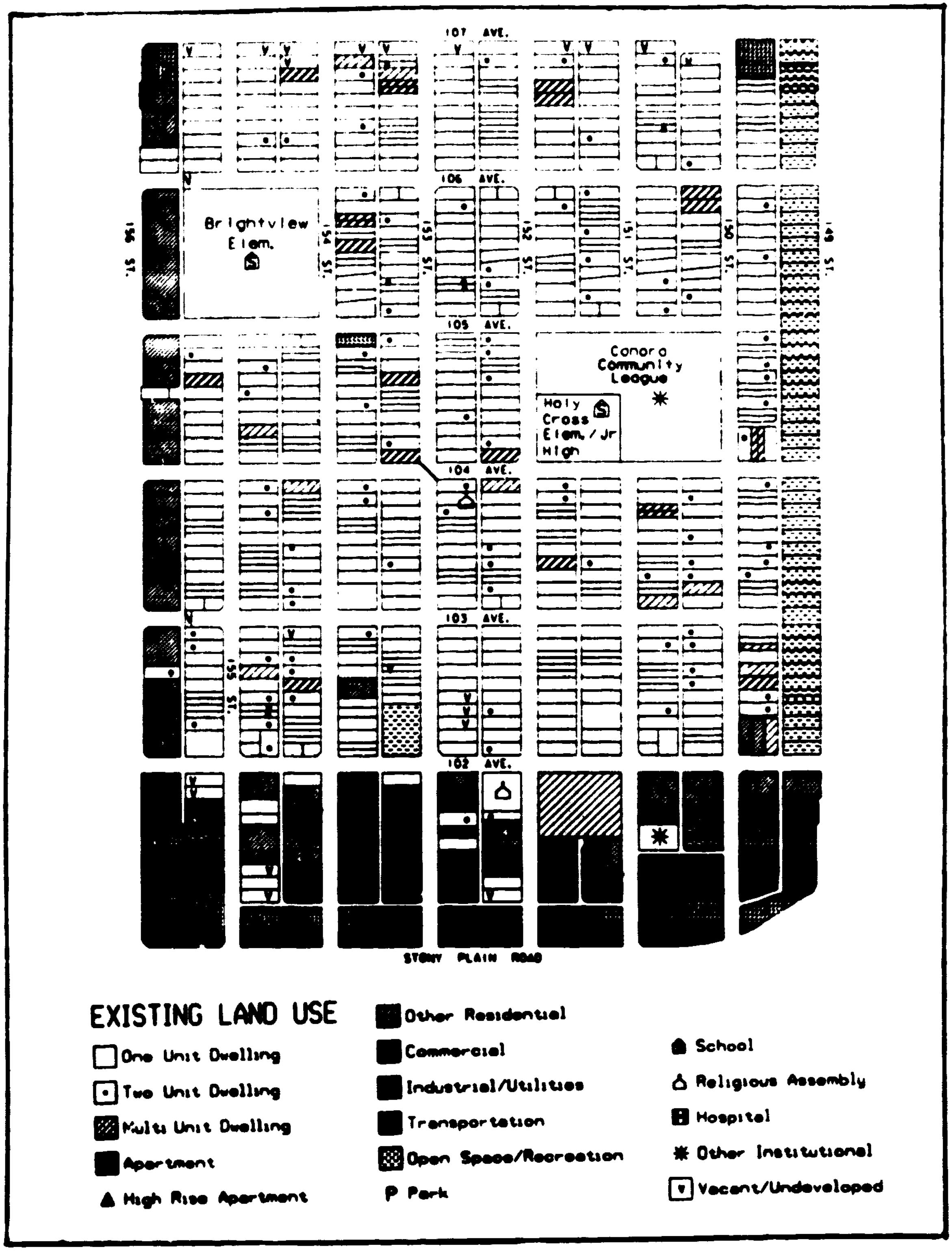

Figure 3.3 Canora, a grid neighbourhood in Edmonton

Source: Edmonton Planning Department, 1987

all four corners, with no parking facilities, and built up to the limits without regard to traffic safety". Incompatible land uses were often located in these residential areas as well, and were poorly segregated from the surrounding dwellings and service facilities.

There were many problems associated with this type of residential environment, which have warranted redevelopment action since 1960. Two major problems identified in almost all such areas are heavy through traffic and deficiencies in service facilities, including parks and open spaces. Redevelopment actions have included (1) selective closure of residential streets to deter through traffic; (2) buying small, scattered groups of lots to make up park deficiencies; and (3) replacement of detached houses along arterial streets by apartment buildings or landscaped buffer zones (see 156 Street and 149 Street in Figure 3.3). None of these actions were without problems. For instance, street closure often caused inconvenience for local residents; scattered small parks were mostly unsuitable for youngsters to play competitive games; infill development with multi-family dwellings made local park spaces even more inadequate; and the location of the apartment buildings exposed more households to traffic hazards on arterial streets.

Finally, while all grid neighbourhoods resemble one another in their regular street layouts, they vary in other aspects of their local environmental configuration. For example, the development of apartment strips along arterial streets did not occur in all grid neighbourhoods (McCann, 1975); and while many grid neighbourhoods front on commercial ribbons, some do not. In other cases, arterial streets cut through neighbourhoods, and some of these are also lined with retail facilities and apartments. From the perspective of the thesis research, variations of this kind may be significant enough to result in different pedestrian accident situations among grid neighbourhoods. For instance, pedestrians can be expected to cross streets more frequently on apartment strips and commercial ribbons than on normal streets, thus intensifying pedestrian-vehicle conflicts.

3.2 Development on Neighbourhood Uni ~rinciples: 1950-Mid 1960s

In 1949, Edmonton City Council, realizing that its established planning mechanisms would be ineffective in the new growth period that was then beginning, appointed two professors (Harold Spence-Sales and John Bland) from McGill University to advise them on the state of physical development and administration under the 1929 Town Planning Act. Among their suggestions were the following:

1) revoke the 1933 Zoning Bylaw, and prepare an official general plan with a new zoning bylaw to implement it;
2) abolish the old Town Planning Commission, and set up a technical planning board and a professionally-staffed planning department to carry out local

planning duties (Bland and Spence-Sales, 1949). This provided the foundations from which the present planning administration developed. It led to the establishment of the City Planning Department in late 1949 (Dant, 1954) and the Technical Planning Board in 1950 (Chan, 1969). Both exerted an immediate influence on residential planning in Edmonton.

At the beginning of this period, Edmonton was ringed by thousands of hectares of undeveloped or partially developed land subdivided on the grid system (the aftermath of land speculation as far back as the first decade of the century). To correct the problems of past subdivision and to provide better residential environments in future, Edmonton began to implement replotting schemes (Dant, 1954). These were legal instruments that permitted the resubdivision of undeveloped land into a form more appropriate to the adoption of neighbourhood unit principles (Hodge, 1991:242). In brief, the old subdivision plans were cancelled, completely new plans were drawn up, and the land was reapportioned to the surviving owners. This procedure was greatly simplified in Edmonton's case by the fact that the areas suitable for replotting were largely owned by the City as a consequence of tax delinquency (Dale, 1969). This control also facilitated the adoption and implementation of the neighbourhood unit concept. The neighbourhood plans were prepared by the City Planning Department and approved by the Technical Planning Board, and development was managed by the City Land Department (Chan, 1969). The first planned unit, Parkallen, was begun in 1950, but neighbourhood unit principles were quickly extended to all other areas of the city. (See Figure 3.2.)

Compared with grid subdivisions, the neighbourhood units could provide many amenities with no great loss of building lots because a curvilinear street layout consumes less land than a grid layout. Blocks are larger on average and minor access streets are narrower. The land so saved was then used for parks, school sites, churches, shopping areas, and even landscaped buffer zones and boulevards to insulate peripheral houses on boundary streets. Take the Sherbrooke neighbourhood for example (see Figure 3.4 and Table 3.1); after replotting, its internal street area was reduced by 15.5 acres (27 per cent), while school sites with affiliated playgrounds and parks increased by 11.9 acres (566 per cent) and other local services by 4.1 acres (216 per cent).

Individual neighbourhood units were commonly organized around an elementary school and adjoining playing fields and parkland, and they were bounded by arterial streets or such physical barriers as ravines and open areas. Their streets were in curvilinear forms and were ordered hierarchically. Blocks were still in conventional format with a central back lane, but most of them took irregular shapes due to the curvilinear street patterns. The number of neighbourhood entrances/exits was greatly reduced (in Sherbrooke, from 25 to 5), which in concert with the internal curvilinear, hierarchi-

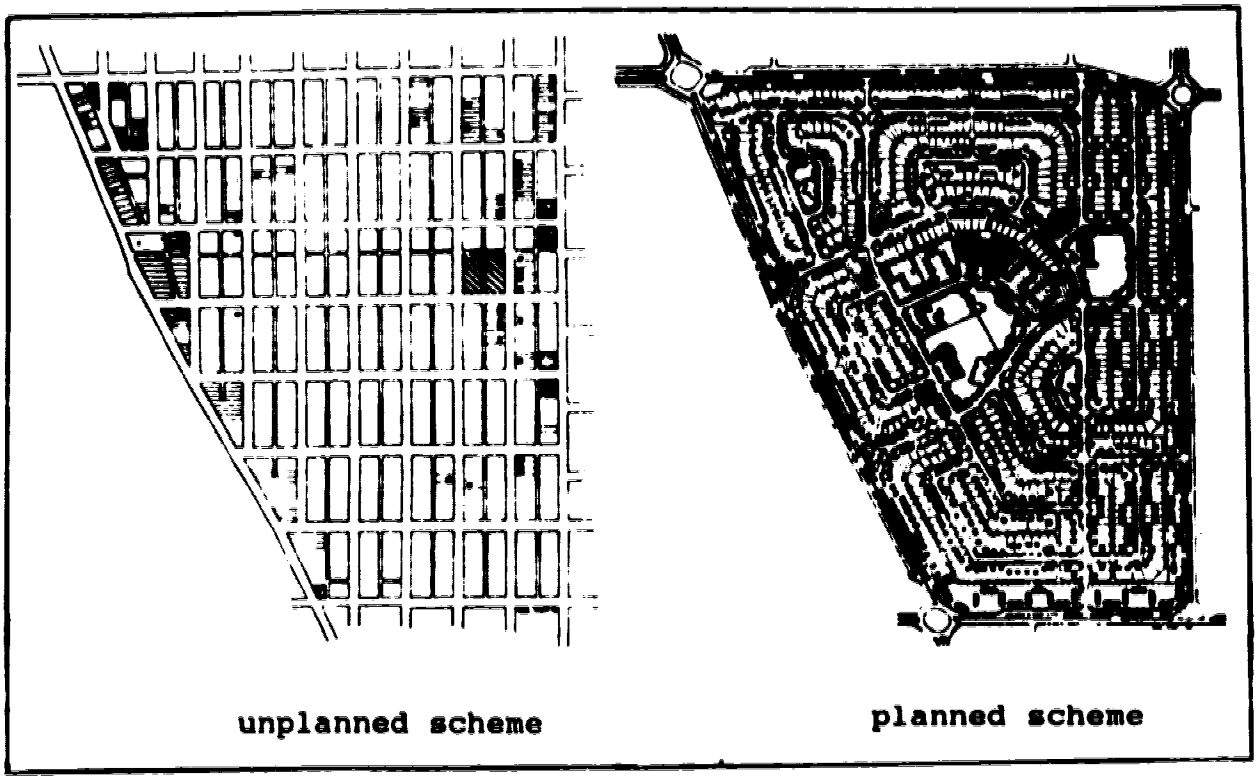

Figure 3.4 Sherbrooke neighbourhood in Edmonton, before and after replotting

The unplanned scheme (before replotting) is a typical grid subdivision and shows the state of development in 1949; the planned scheme illustrates how the same land was replotted following neighbourhood unit principles.

Source: Map prepared for the Community Planning Association of Canada by the Edmonton City Planning Department, 1955

Table 3.1
Comparative statistics for Sherbrooke, Edmonton before and after replotting

Land use types	Unplanned scheme (before replotting)	Planned scheme (after replotting)
Internal roads	57.2 acres	41.7 acres
Service lanes	12.6 acres	10.7 acres
Public school space	2.1 acres	6.0 acres
Separate school space	0 acres	4.0 acres
Community league	0	2.0 acres
Parks	0	4.0 acres
Churches	0	1.5 acres
Shopping areas	1.9 acres (scattered)	2.5 acres
Agricultural zone	19.0 acres	0 acres
Light industry	6.6 acres	0 acres
Miscellaneous (e.g. planted buffers on boundary streets)	0 acres	10.6 acres
Residential single-family row-housing apartments total units gross density	122.6 acres (1,068 units) (0 units) (0 units) (1,068 units) 4.8 units/acre	139.0 acres (896 units) (245 units) (190 units) (1,331 units) 6 units/acre
Total	222.0 acres	222.0 acres

Source: Map prepared for the Community Planning Association of Canada by the Edmonton City Planning Department, 1955

cal streets and T-intersections made through traffic difficult. Boundary streets, where heavy traffic was expected, were mostly buffered with service roads. Apartment buildings were mostly grouped in clusters (rather than in the form of strips as in some grid subdivisions) and located near neighbourhood shopping centres or schools for easy pedestrian access to local facilities. (The only exception is in Sherbrooke, where apartment buildings align 118 Avenue, but even there they are set back with a service road in front.) Internal pedestrian circulation was mainly accommodated on paved sidewalks. Inter-neighbourhood pedestrian linkages received inadequate consideration, however, because individual neighbourhood units were designed independently, with little thought for their functional relations with adjacent neighbourhoods.

One especially important feature of Edmonton's earliest neighbourhood units is that they were developed on lands that were partially occupied with permanent structures (see the "unplanned scheme" in Figure 3.4). The replotting schemes had to accommodate these properties into the neighbourhood unit plans, and some original streets were therefore retained, giving rise to what are referred to in Edmonton as modified-grid neighbourhoods (see the example of Belgravia in Figure 3.5). As a transitional type, these neighbourhoods vary considerably in their street layouts: some of them resemble grid neighbourhoods with numerous entrances/exits and cross-intersections; many have more similarities with the true neighbourhood units with limited numbers of entry points and a preponderance of curvilinear streets and T-intersections. In their land use organization, however, modified-grid neighbourhoods are most like neighbourhood units. The replotting

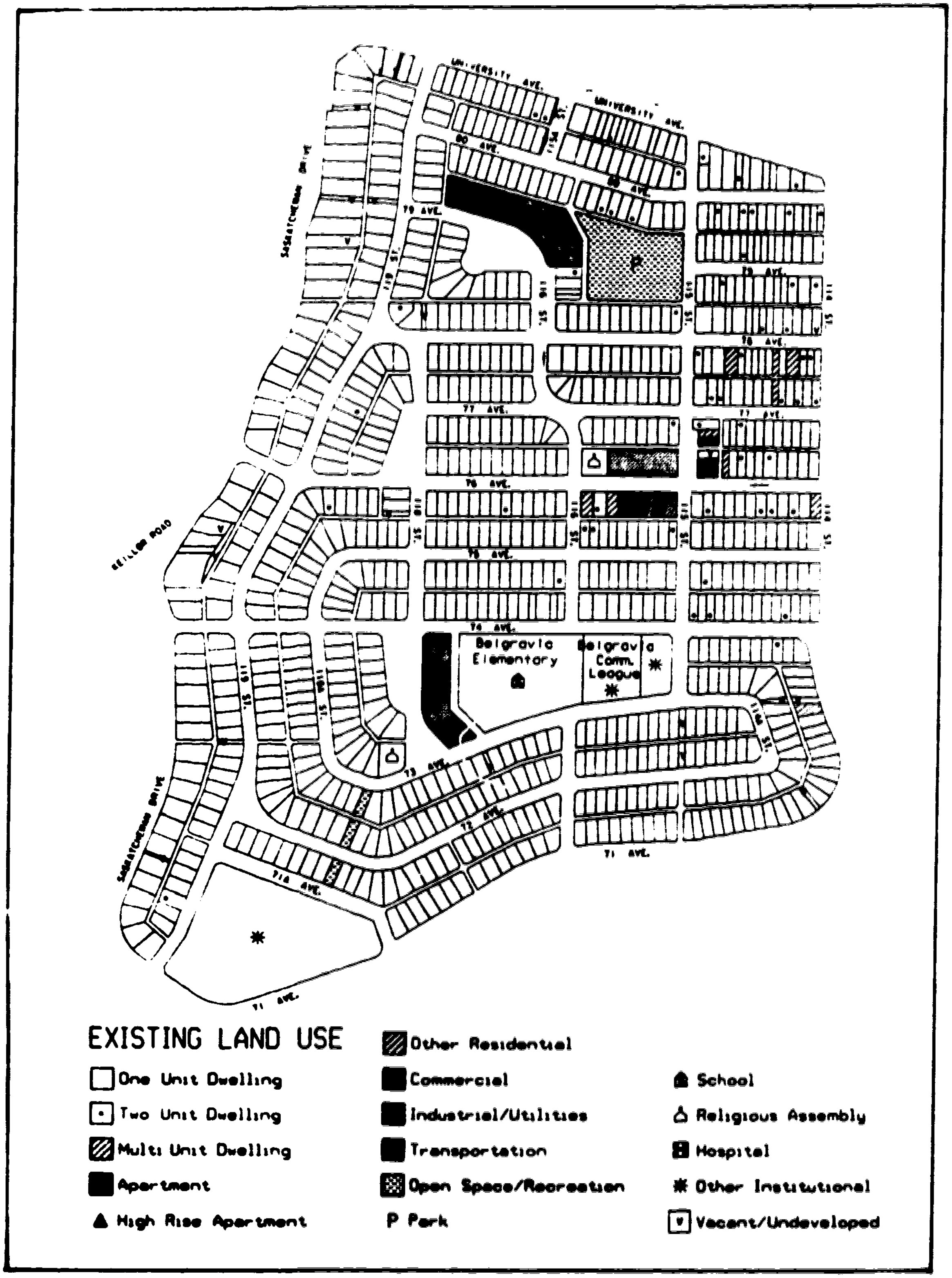

Figure 3.5 Belgravia, a modified-grid neighbourhood in Edmonton

Source: Edmonton Planning Department, 1987

procedure allowed sites to be secured for local service facilities and multi-family housing in accordance with Perry's principles, and simultaneously prevented the development of features that the planners of the day regarded as undesirable, such as commercial ribbons.

Every planned neighbourhood, including those of modified-grid form, was individually designed to suit its particular site conditions. The neighbourhoods developed in this period therefore exhibit much variation in their detailed forms. For instance, while most of them are bounded on three or four sides by arterial roads, which also serve to separate adjoining units, some are bounded in part by natural barriers (such as ravines and open spaces). In a few cases, as well, houses along arterial boundary roads were reversed to face internal streets, rather than a perimeter service road. (For an example, see the northern boundary of Sherbrooke in Figure 3.4). The locations of neighbourhood shopping centres vary also; sometimes (reflecting Dant's English background) they were placed in the centre of a neighbourhood, but more often (as Perry proposed) there are at main entry points or a corner, at the intersection of two arterial streets. The pattern of development has been made even more complicated by the addition of district and regional shopping centres which serve trade areas much larger than a single neighbourhood. Since they attract large volumes of external traffic, they are considered as incompatible land uses in their host neighbourhoods. A final but particularly important variation relates to the organization of educational services. Edmonton has two parallel school systems: one consists of public schools, the other of separate (Catholic) schools. Each system is structured with a 3-level hierarchy: elementary, junior high and senior high. This has two implications. First, while most neighbourhood units were planned as the service area of a public elementary school, several neighbourhoods are required to support either a junior or a senior high school. As a result, some neighbourhoods host high schools, others do not. Second, the population of separate school students in Edmonton is less than half that of public school students. This means that two neighbourhood units normally share one separate elementary school, and many more share one separate high school. Again, some neighbourhood units host separate schools, but many do not. These variations are expected to affect local (especially inter-neighbourhood) pedestrian movement patterns, and must be considered when pedestrian accident patterns are interpreted.

3.3 Hierarchical Structures Designed on the Separation Principle: Mid-1960s to the Late 1970s

Edmonton was growing rapidly in the mid-1960s. Residential development was then expanding in three directions, south, west and north. To provide public services more efficiently and cost-effectively, a completely new planning approach was adopted for suburban residential development.

This was to exercise large-scale planning and to organize residential areas with hierarchical structures (Graden, 1979).

In 1966, the draft of the long-awaited comprehensive plan was published. Although not adopted until 1971, it set out Council's major policies concerning Edmonton's future growth and development, and the concept of hierarchical organization of residential areas was prescribed for the first time as a development principle. In the words of the plan, "Careful study must be given to the design of each new neighbourhood in relation to the next, and to the convenient grouping of neighbourhoods into residential districts" (Edmonton Planning Department, 1966:48). The City of Edmonton then embarked on the preparation of a series of plans for the development of its suburban districts, including the West Jasper Place Outline Plan (1967), the Castle Downs Outline Plan (1970), the Casselman-Steele Heights District Outline Plan (1971), the Kaskitayo Outline Plan (1971), Mill Woods: A Development Concept Report (1971), and the Riverbend-Terwillegar Heights District Outline Plan (1977). (See Figure 3.2 for these planning areas.) The purpose of these outline plans, as they were then called (they later became known as area structure plans in line with the 1977 Alberta Planning Act), was to translate broad policies of the General Plan to a more refined and intimate scale, and to provide the framework upon which detailed subdivision plans could be based.

Most of the new residential districts that came under development in this period were planned to have a three-level hierarchy of neighbourhood-community-district. Figure 3.6 illustrates this structure for Kaskitayo. The neighbourhood was still the basic organizational unit, but two or three adjacent neighbourhoods formed a residential community, which focused on shopping and secondary education facilities as well as separate elementary schools. The number of communities varied in different districts. For instance, there were eight in Mill Woods, but only three in Kaskitayo. In all districts, component communities were organized around a proposed town centre, which was planned to contain a shopping centre (either district or regional), senior high schools, district open spaces and recreational facilities, and social, cultural and health services, as well as high-density housing. Because district development took place in phases and construction slowed down considerably after the early 1980s, none of the town centres has yet been completed as proposed. In fact, the Clareview and Riverbend town centres have not even been started (Christy, 1987).

Associated with the hierarchical organization of neighbourhoods and communities was a more clearly-defined street hierarchy that consisted of (from high to low) arterial streets, collector streets and local access streets (see the proposed hierarchical street system for Mill Woods District in Figure 3.7). Arterial streets were used to delimit the planning district and divide it into communities. Their main

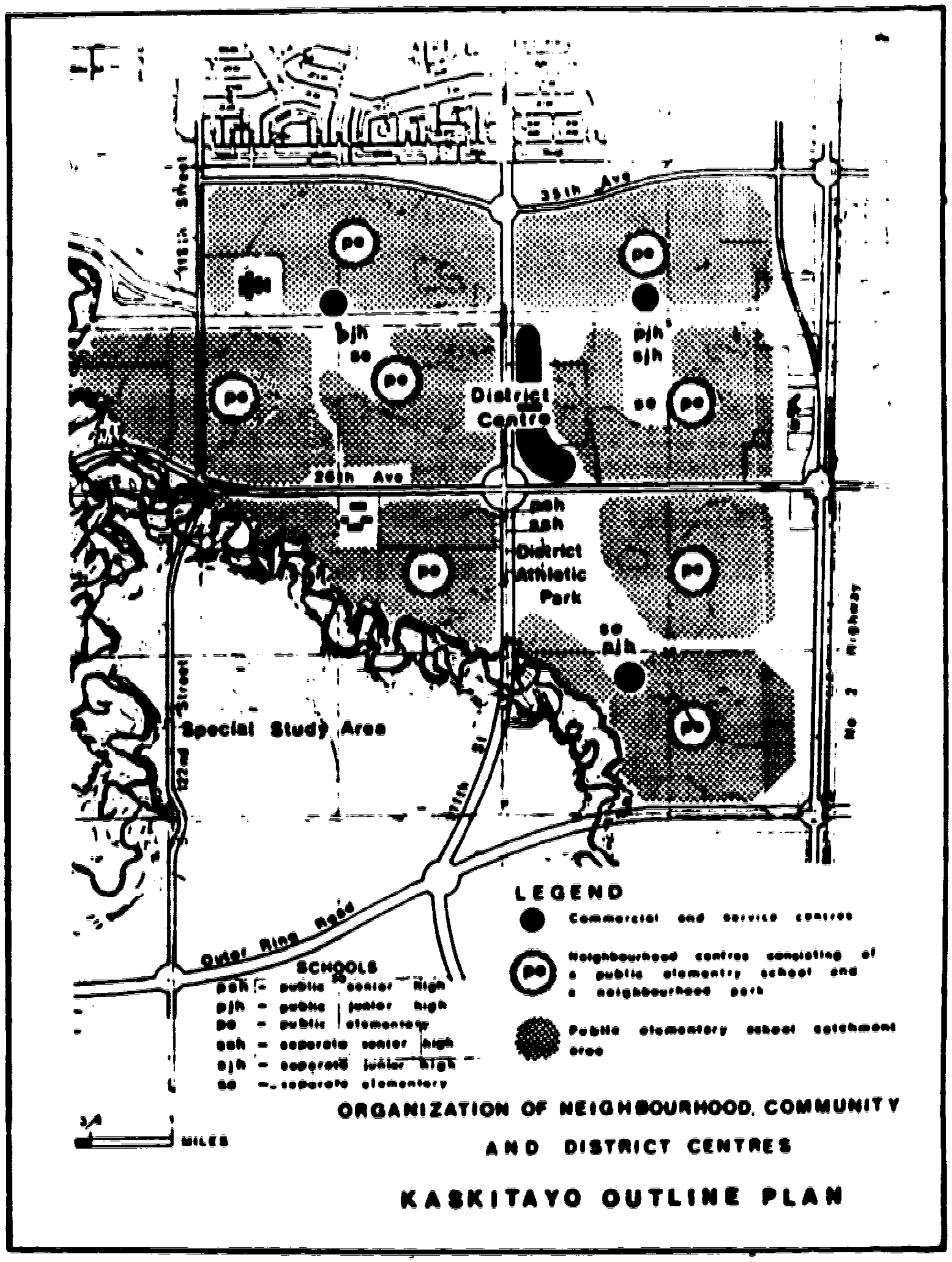

Figure 3.6 Hierarchical organization of neighbourhoods for Kaskitayo, Edmonton

Source: Underwood McLellan & Associates Limited, 1971:Plate 5

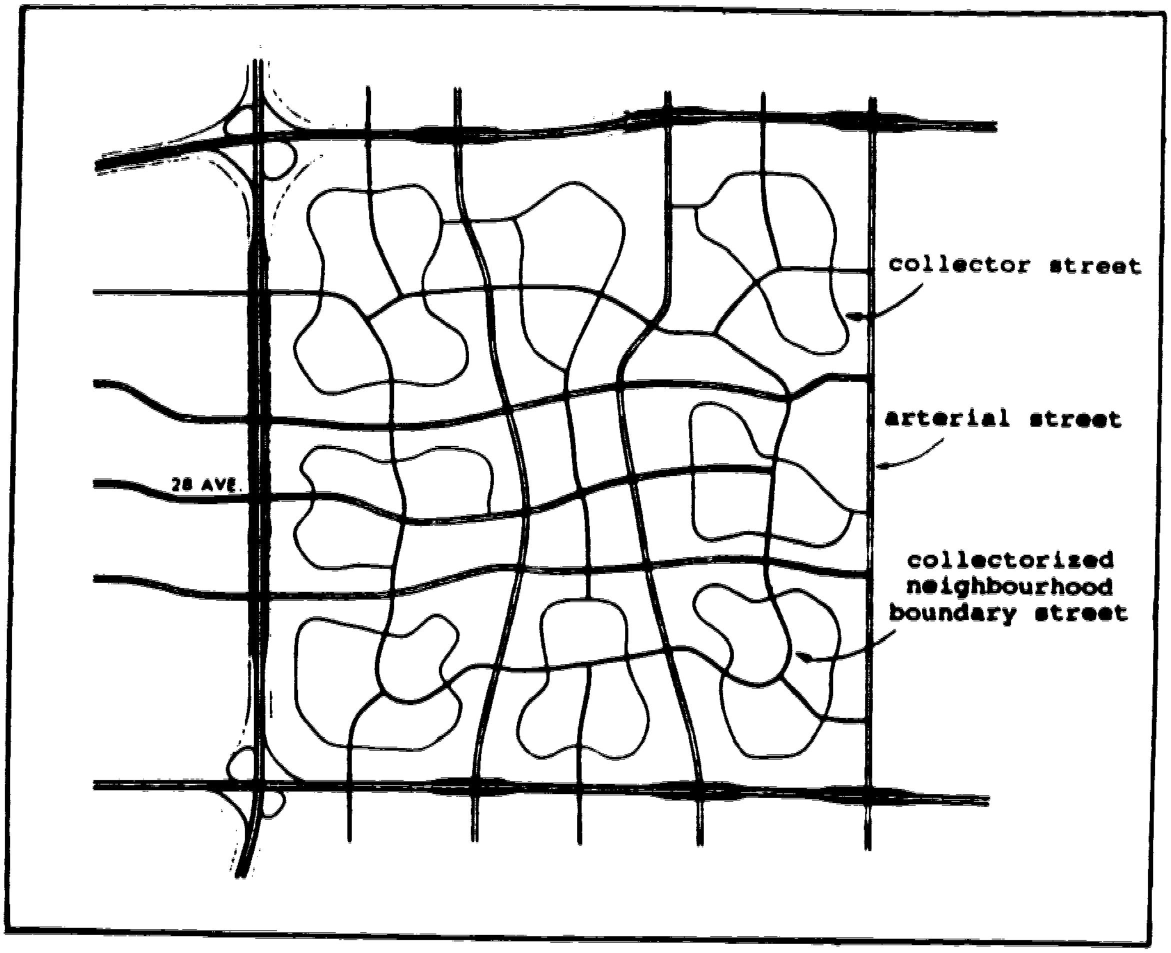

Figure 3.7 Proposed hierarchical street system for Mill Woods District, Edmonton (no access streets are shown). This district consists of 8 compact communities around a town centre, each being separated by arterial streets.

Source: Edmonton Planning Department, 1971:4.3

function was to channel through traffic. Collector streets formed neighbourhood boundaries within communities and also penetrated neighbourhoods to provide local bus routes, along which major local service facilities (e.g. schools, parks, or shopping centres) and multi-family dwellings were situated (see the example of Millbourne Road East in Figure 3.8). By contrast, only minor streets, mainly in the form of culs-de-sac or short loops, provided direct access to single-family houses. Since no residential structures were built fronting on arterial streets, service roads were unnecessary. Instead, houses were mostly insulated from arterial streets by berms or planted buffers, sometimes combined with concrete noise walls which completely block pedestrian traffic.

Another important characteristic of suburban residential development in Edmonton in this period was the strong influence of the Radburn concept, though not exactly as Stein and Wright devised it. While the idea of separate footpath networks was retained, other original Radburn features were varied and blended with cluster subdivision principles to create a modified form of Radburn neighbourhood, as illustrated in Figure 3.8. For instance, not all residential blocks were laid out as superblocks. Instead, superblocks usually formed the core blocks of a neighbourhood, where the elementary school, park, multi-family dwellings and even shopping centres were located. Informal cluster blocks then surrounded the superblocks. Residential buildings were mostly grouped

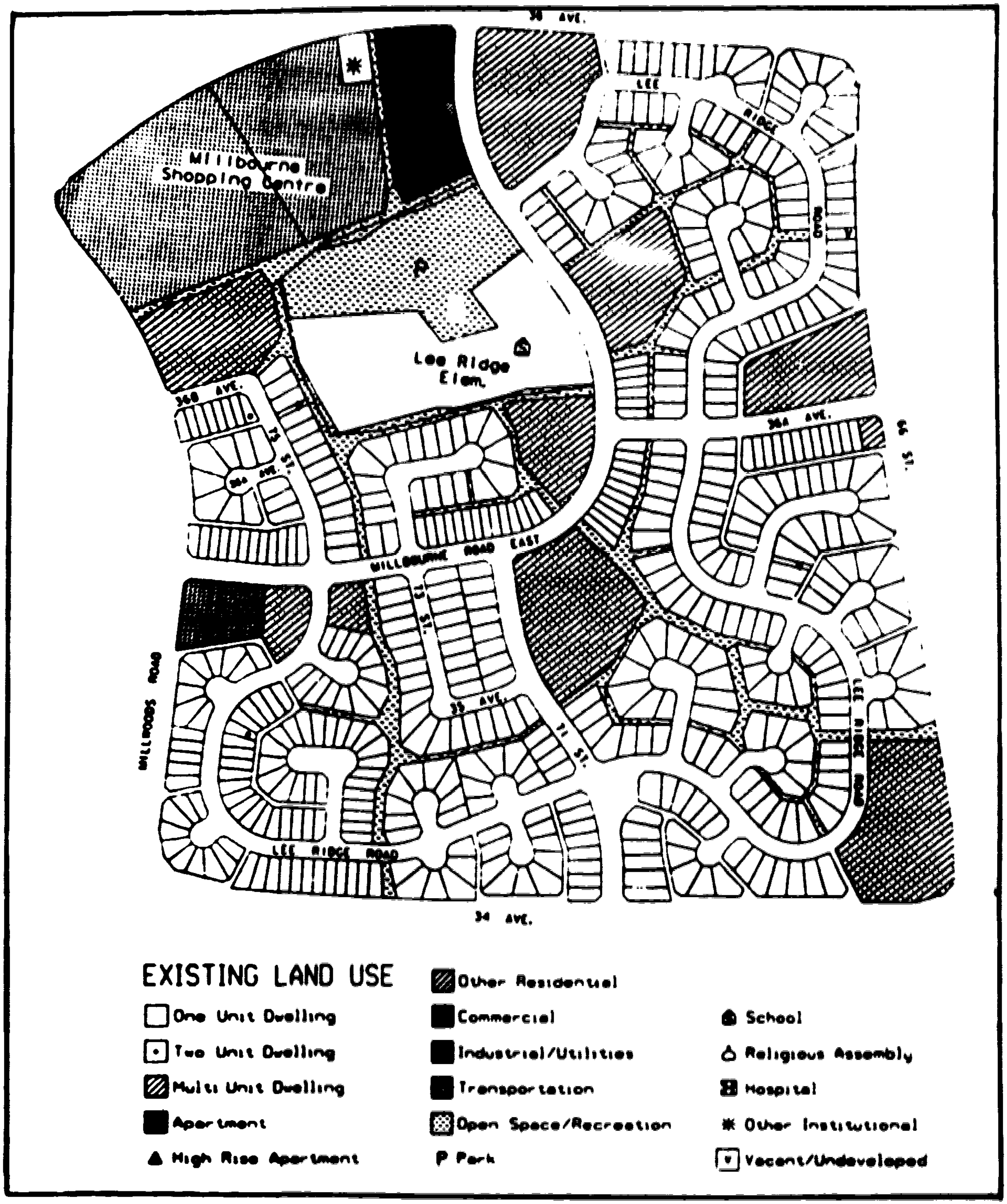

Figure 3.8 Lee Ridge, a modified-Radburn neighbourhood in the community of Millbourne, Mill Woods

Source: Edmonton Planning Department, 1987

around culs-de-sac or along short-loop access streets, but in most cases they were not reversed to face internal open spaces and footpaths as in Radburn.

Almost all the outline plans from this period emphasized the separation approach as the primary principle for the provision of pedestrian facilities. Its standard form was described as a "spinal walkway system consisting of major walkways [separate footpaths] which are directly connected to access walks and sidewalks" (Edmonton Planning Department, 1968b:2). Figure 3.9 illustrates the walkway network proposed for the community of Springfield, West Jasper Place, and shows how it was intended to connect houses with parks, schools and other service facilities, not just within individual neighbourhoods but throughout the whole suburban district. Part of the network actually constructed in the community of Millbourne, Mill Woods is illustrated in Figure 3.8; it demonstrates how thoroughly the pedestrian paths were segregated from vehicular traffic. It was also intended, in the original schemes, that grade-separated underpasses should be installed where spinal walkways crossed arterial or collector streets (see Figure 3.9), but this rarely materialized in Edmonton. In fact, most walkways cross streets (including arterial streets) at grade, with various forms of traffic control devices. This is another departure from the original Radburn concept.

Finally, a major source of variation in community configuration in Edmonton needs to be mentioned because it is

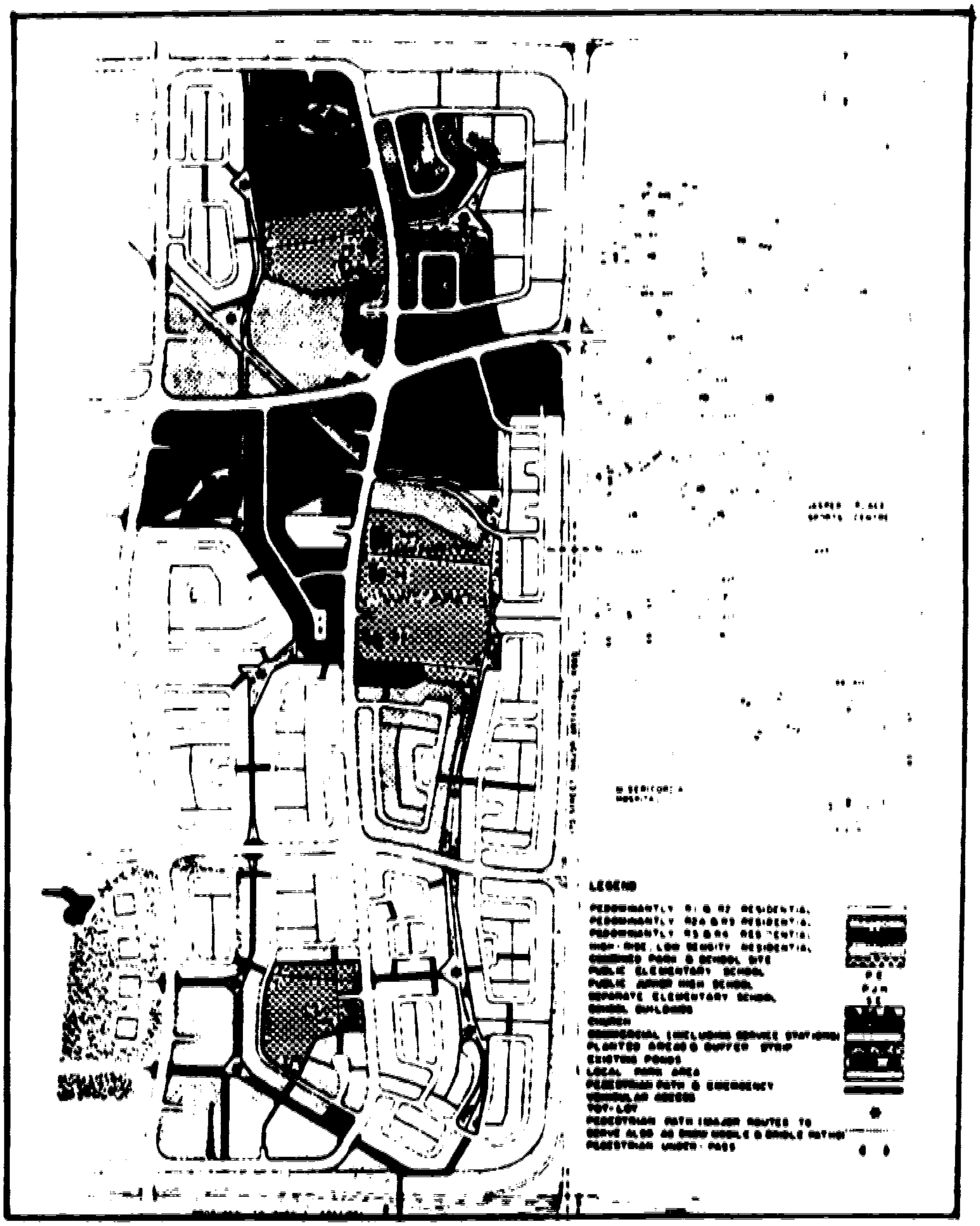

Figure 3.9 A walkway network proposed for the three neighbourhoods comprising the Springfield community in the West Jasper Place district

Source: Edmonton Planning Department, 1968a

considered to bear on pedestrian safety. That is, Edmonton's suburban communities differ in shape. Some communities (such as those in Mill Woods, see Figure 3.7) have compact shapes with circular loops of collector streets; others (such as those in Castle Downs and West Jasper Place, see Figure 3.9) take elongated shapes with elliptical collector loops. Unlike collector streets in independent neighbourhood units which seldom carry through traffic, collector streets in hierarchically structured communities normally carry some through traffic from or to other neighbourhoods. In elongated communities, the collector streets tend to be long and fairly straight and to have open vistas, all of which encourage drivers to speed. This may create special dangers for pedestrians because most pedestrian-oriented service facilities (including schools, playgrounds and neighbourhood shopping centres) lie on these streets.

3.4 Return to the Accommodation Approach to the Provision of Pedestrian Facilities

Through the 1980s, the six suburban districts mentioned previously were still under development, although some new districts were added as well. Residential development during this period continued to follow the principle of hierarchical organization, and neighbourhood configuration resembled that of the modified-Radburn neighbourhoods in terms of street layout, block pattern and land use organization. The most important change, for thesis purposes, was the conscious shift away from the separation approach to accommodation in the provision of pedestrian facilities. The neighbourhoods created in this period are most appropriately called cluster-plan neighbourhoods. An example is given in Figure 3.10.

The change in approach started in the late 1970s. After about 10 years of residential development in which separation was favoured, the City Planning Department (in consultation with the Transportation and Parks and Recreation departments) released a study report on walkway systems (Edmonton Planning Department, 1977b). This identified three major difficulties with respect to the provision and use of separated walkway networks. First, the high costs of walkway development had translated into higher house prices in new areas, thus affecting the housing market. Second, there had been disagreement between developers and the City administration regarding the period over which developers should be held responsible for walkway maintenance. Furthermore, after the developers' period of maintenance was over, no one city department had sole responsibility for maintaining the walkways. For instance, the Transportation Department was maintaining the concrete walks; the Parks and Recreation Department maintained the grass cover, shrubs, trees and benches; Edmonton Power was responsible for walkway lighting; and Edmonton Water and Sanitation removed waste. In a nutshell, there were difficulties of coordination. Third, since residents along footpaths wish to ensure their privacy, they often enclosed their

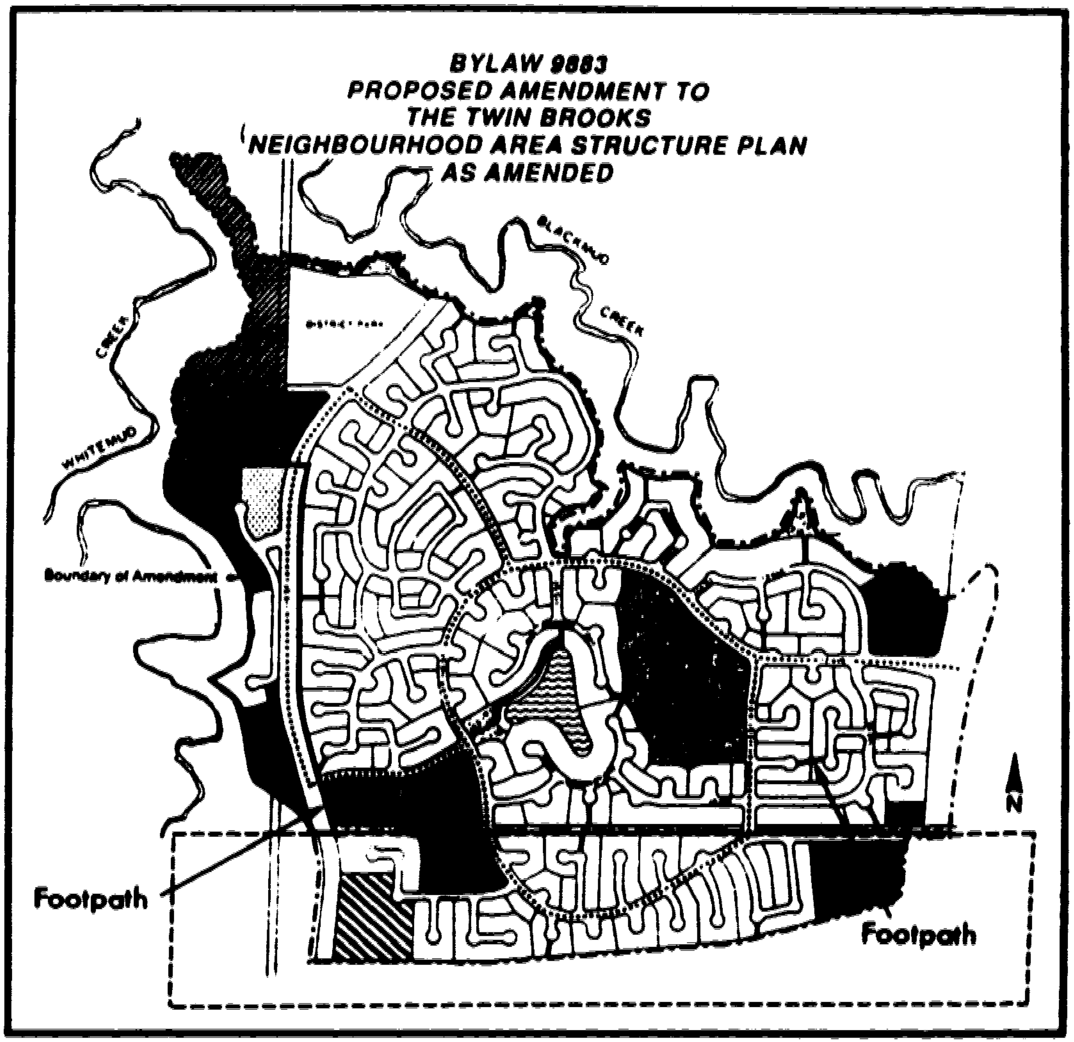

Figure 3.10 Neighbourhood structure plan for Twin Brooks in Edmonton (with occasional footpaths only)

yards with fences. When fences were erected side by side, they made the walkways "no man's land" from a social point of view (Figure 3.11). As a result of these difficulties, the Planning Department recommended that the City support the construction of fewer but more practical walkways in new subdivisions. This marked the beginning of the shift back to the accommodation approach.

The change did not just affect new suburban districts, but applied as well to the undeveloped sections of those districts planned in the 1970s to have separate footpath networks. Characteristically, neighbourhoods developed or planned since then use sidewalks as the major routes for pedestrian circulation. Separate footpaths are provided only occasionally, notably at the heads of culs-de-sac to offer pedestrian shortcuts to parks and bus stops (see Figure 3.10). The new policy was neatly expressed in the West Jasper Place (South) Area Structure Plan (Mackenzie Spencer Associates, 1978:11): "No major walkways are proposed [for this area]. Pedestrians and bicycle movements shall be accommodated on the local road network supplemented by minor walkway connections to serve trips to schools, local shopping and natural areas."

3.5 Classification of Neighbourhoods in Edmonton on the Basis of Environmental Configuration

During the past 100 years or so, residential development in Edmonton has produced a variety of neighbourhood forms, to the extent that all the types described in Chapter 2, with the

Figure 3.11 A footpath bordered by fences, in Lee Ridge neighbourhood in Mill Woods

exception of the genuine Radburn form, can be found there. In addition, a transitional type of neighbourhood, the modified grid, resulted from the replotting schemes of the early 1950s. Specifically, the following 5 types of neighbourhoods can be distinguished in Edmonton. They constitute a ready classification scheme of residential environments for evaluation purposes:

1. Grid neighbourhood
2. Modified-grid neighbourhood
3. Independent neighbourhood unit of conventional form
4. Modified-Radburn neighbourhood unit
5. Cluster-plan neighbourhood unit.

The grid neighbourhoods have no formal land use organization. Many of them are associated with commercial ribbons and apartment strips, or are adjacent to incompatible land uses. Grid streets with small, rectangular blocks naturally result in high street density, high intersection density (mostly cross-intersections), and numerous neighbourhood entrances/exits. A number of grid neighbourhoods are even cut through by well-established arterial streets. Narrow, discontinuous sidewalks are the major form of pedestrian facilities.

In the modified-grid neighbourhoods, the land use pattern is partially structured, with centrally-located schools, neighbourhood shopping centres and clustered multi-family dwellings. Yet, the unmodified parts are in some cases still associated with the typical features of unplanned residential environments, such as commercial ribbons, apartment strips and incompatible land uses. Street layouts and boundary treatments also vary considerably, depending on the degree of modification from the original grid form. Pedestrians are accommodated on conventional sidewalks.

The independent neighbourhood units in Edmonton were built in general accordance with Perry's principles. Each unit is centred around a public elementary school and separated from others by either arterial streets or natural barriers. Shops and multi-family dwellings are deliberately clustered, rather than in the form of ribbons along arterial streets. No incompatible land uses other than district or regional shopping centres exist in the close vicinity of these units. Streets are all in curvilinear forms with hierarchical ordering, but blocks are still of conventional format though with irregular shapes. Virtually no neighbourhood units are cut through by arterial streets; Crestwood, which straddles 142 Street, is the only exception. Sidewalks form complete pedestrian circulation networks on the accommodation principle.

Modified-Radburn and cluster-plan neighbourhoods both form elements of larger, hierarchically-organized units. They are also characterized by similar land use patterns, block patterns and street layouts. In general, they centre on the site of a public elementary school, but other facilities concentrate in community or town centres. Normally, a superblock forms the core block of each neighbourhood, surrounded by cluster-blocks. The component neighbourhoods in each community are connected by a continuous collector street which also serves public transit. Local access streets are mostly in the forms of culs-de-sac and short loops. The only difference in the configuration of these two types of neighbourhoods is in their distinctive forms of pedestrian circulation networks: the former have extensive separate footpath networks, while the latter use sidewalks as the major routes for pedestrian circulation, with only occasional short footpaths. In the modified Radburn neighbourhoods, grade-separated pedestrian crossings, which were favoured in the original Radburn concept, have rarely materialized. Instead, most walkways cross streets (including arterial streets) at grade, with various forms of traffic control devices. From the standpoint of pedestrian safety, these modifications require pedestrians to cross more streets at grade than in a typical Radburn neighbourhood. As a consequence, the differences in safety effects between the genuine Radburn model and cluster-plan neighbourhoods may not be fully revealed through an Edmonton case study.

It must also be emphasized, as in North American cities in general, that although Edmonton's neighbourhoods were built on the planning principles or concepts that prevailed at the time of development, they were never designed to fixed models with identical physical layouts. That is, neighbourhoods of serves public transit. Local access streets are mostly in orms of culs-de-sac and short loops. The only difference e configuration of these two types of neighbourhoods is eir distinctive forms of pedestrian circulation networks: ormer have extensive separate footpath networks, while atter use sidewalks as the major routes for pedestrian lation, with only occasional short footpaths. In the ied Radburn neighbourhoods, grade-separated pedestrian ings, which were favoured in the original Radburn pt, have rarely materialized. Instead, most walkways streets (including arterial streets) at grade, with us forms of traffic control devices. From the standpoint destrian safety, these modifications require pedestrians oss more streets at grade than in a typical Radburn bourhood. As a consequence, the differences in safety ts between the genuine Radburn model and cluster-plan bourhoods may not be fully revealed through an Edmonton study.

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CHAPTER 4

RESEARCH HYPOTHESES AND STUDY PLAN

This chapter consists of 3 parts: the first part states the research hypotheses; the second explains the study procedures and methods by which the hypotheses are to be tested; the third describes the data sources used in the thesis research.

4.1 Research Hypotheses

To reiterate, the general objectives of the thesis research are (1) to evaluate the relative safety of different forms of residential environment, using neighbourhoods as the units of analysis, (2) to assess the respective effectiveness of the alternative forms of the four critical design elements, and (3) to determine whether variations in the degrees of pedestrian safety among individual neighbourhoods of the same general type can be attributed to local differences in their environmental configurations. In Chapter 2, the various forms of the environmental design elements were identified, along with different design concepts that have given rise to distinctive type configurations. Their applications in Edmonton were then described in Chapter 3, to set the local context for the research problem, and above all, to construct an appropriate typology of Edmonton's neighbourhoods. From this background, 3 sets of hypotheses are now formulated. The first set, which is in accordance with the first research objective, relates to general neighbourhood forms and their relative effects on pedestrian safety. The second postulates associations between the incidence of pedestrian accidents and different aspects of circulations networks, both vehicular and pedestrian; it partially addresses the second research objective. The third, which relates to both the second and the third research objectives, concerns the safety implications of major variations in local environmental configuration, including land use effects.

4.1.1 Hypotheses Relating to General Neighbourhood Form

This set of hypotheses focuses on the relative safety of different types of neighbourhoods, classified on the basis of their characteristic environmental configurations. As established in Chapter 3, residential development in Edmonton, as in North American cities in general, progressed from unplanned subdivisions to planned neighbourhoods of various types. Remember, when Clarence Perry invented the neighbourhood unit concept, he conceived a particular combination of environmental forms to promote pedestrian safety, such as a centrally located elementary school within walking distance from the homes in its intended service area, together with a curvilinear street network organized into a functional hierarchy. These features were so influential that they were retained as necessary characteristics for all forms of planned neighbourhoods developed thereafter. Of the planned neighbourhoods of all forms, however, those incorporating Radburn features (notably, superblocks and separate footpaths) have long been considered to provide the safest pedestrian environment, especially when used in a hierarchical structure. From these normative assumptions the following 5 hypotheses result:

1. Mean pedestrian accident rates are significantly higher in unplanned (or grid) neighbourhoods than in planned neighbourhoods. In the former, grid streets tend to invite through traffic. Moreover, pedestrians there have to cross many streets, including heavily trafficked streets, to reach local service facilities such as schools, playgrounds and shops. In contrast, planned neighbourhoods with curvilinear and hierarchical streets discourage through traffic and provide their residents with convenient pedestrian access to the facilities within the neighbourhood, especially the elementary school. (See Section 3.5 for detailed differences in characteristic environmental configurations between unplanned and planned neighbourhoods in Edmonton.) In theory, the latter should be much safer for pedestrians than the former.

2. As a transitional type between unplanned and fully planned neighbourhoods, modified-grid neighbourhoods have mean accident rates lower than grid neighbourhoods but higher than planned neighbourhoods of all types.

3. Independent neighbourhood units have significantly higher mean pedestrian accident rates than the hierarchically

organized modified-Radburn and cluster-plan neighbourhoods. Theoretically, this difference should result mainly from their respective patterns of inter-neighbourhood organization. The former are seldom self-contained, yet they are often separated by busy arterial streets from those neighbourhoods with which they share facilities. Consequently, inter-neighbourhood pedestrian trips result in a high exposure to traffic hazards, especially the most regular trips made by school-age children. In areas of hierarchical organization, by contrast, although inter-neighbourhood pedestrian trips are still necessary, neighbourhood boundary streets are either highly insulated with strictly limited pedestrian accesses (in the case where they are also community boundaries) or they are collector streets designed for intra-community traffic only.

4. Among the hierarchically organized neighbourhoods, those of the modified-Radburn type with separate footpaths have lower mean pedestrian accident rates than the cluster-plan neighbourhoods without separate footpaths. Because footpath networks separate pedestrians from streets, the potential for conflict between pedestrians and vehicles on residential streets should in theory be minimized, making modified-radburn neighbourhoods the safest type of all in Edmonton.

5. Neighbourhoods consisting of a mix of superblocks and cluster blocks (i.e. the modified-Radburn and cluster-plan types) have lower mean intra-neighbourhood pedestrian accident

rates than those composed of conventional blocks (including independent neighbourhood units as well as grid and modified-grid neighbourhoods), with the neighbourhoods with separate footpaths (the modified Radburns) having the lowest mean intra-neighbourhood rate. In the first group of neighbourhoods, such local service facilities as schools, playgrounds and community halls are usually located in superblocks and pedestrian users have to cross fewer streets to reach them. Where separate footpaths are provided as well, in the modified-Radburn neighbourhoods, the potential for conflict between pedestrians and vehicles on internal streets is reduced still further. (Hypothesis 5 is different from Hypotheses 3 and 4 in that it tests the relative safety of neighbourhood interiors resulting from variations in block types and associated variations in internal street patterns.)

The above 5 hypotheses will be tested for different age groups as well as for total neighbourhood populations, to find out if the "safer" forms of planned residential environment benefit all segments of the neighbourhood population, especially children and elderly people, who are particularly vulnerable to pedestrian accidents.

4.1.2 Hypotheses Relating to Circulation Networks

Circulation networks, both vehicular and pedestrian, need special attention in the thesis research for two reasons. First, all accidents happen on streets, at locations where street networks and pedestrian facility networks intersect or coincide; it is therefore logical to presume (as already indicated from the previous studies reviewed in Section 2.2.3) that the varying forms of these two design elements will have major implications for pedestrian safety. Second, of the four design elements, it is the combination of street patterns and pedestrian networks that most clearly differentiates Edmonton's 5 neighbourhood types from one another. Revealing the safety effects of their differing forms should therefore be an important step towards explaining whatever differences are actually found when the different types of neighbourhoods are compared. Indeed, comparing the mean pedestrian accident rates of neighbourhood types, as proposed in the first set of hypotheses, does not explicitly demonstrate the effectiveness of those features of circulation systems that urban planners have been particularly concerned to manipulate. Based on the information presented in Section 2.3.1.1, a second set of hypotheses has been formulated to focus on the safety implications of the various forms of such critical features as street type and density, intersection type and density, and the number of neighbourhood entry points. The safety implications of separate footpath networks are considered as well.

6. <u>There are positive correlations between pedestrian accident rate and (1) street density, (2) intersection density, and (3) the number of neighbourhood entrances/exits; for this reason, the rank of mean pedestrian accident rates</u>

matches the ranks of these three street-related factors among different types of neighbourhoods. Since conflicts between pedestrians and vehicles occur on streets, it is logical to postulate that the higher the density of streets in a residential neighbourhood, the more chances there are for pedestrian accidents. This is true also for intersection density, because intersections are where most crosswalks are located and vehicles arrive at intersections from several directions, which leads to high pedestrian accident risk. The negative effects of multiple neighbourhood entrances/exits are two-fold: on boundary streets which are mostly arterials, more entrances/exits mean more intersections, which makes the control of fast-moving vehicles and the facilitation of inter-neighbourhood pedestrian trips very difficult; for neighbourhood interiors, numerous entrances/exits tend to invite through traffic, which is a major threat to pedestrian safety on collector streets and access streets, as observed by European studies. Since street density, intersection density and the number of neighbourhood entrances/exits are all deliberately reduced in planned neighbourhoods, and especially in the modified Radburn and cluster-plan neighbourhoods where superblocks and cluster blocks prevail, pedestrian accident rates should display a corresponding decrease.

7. (a) Most pedestrian accidents in residential areas happen on neighbourhood boundary streets; (b) in relation to typical neighbourhood forms, the boundary streets of unplanned

grid neighbourhoods court more pedestrian accidents than those of planned neighbourhoods, and the proportion of accidents on boundary streets is significantly higher in the areas laid out as independent neighbourhood units than in areas of hierarchical organization. Since most boundary streets are arterials, their heavy loads of fast-moving through traffic pose a great threat to cross-street pedestrian movement, an observation made by the European studies reviewed in Section 2.2.3. The boundary streets of grid neighbourhoods are assumed to be the most hazardous because, in addition to unsafe land use features such as commercial ribbons and apartment strips, they are characterized by closely-spaced intersections which also constitute neighbourhood entrances. The boundary streets of independent neighbourhood units are expected to be less safe than those of neighbourhoods belonging to hierarchical structures mainly for the reasons stated in Hypothesis 3.

8. Of the various forms of streets that provide direct access to houses, culs-de-sac are the safest for pedestrians, and short-loop streets are safer than straight through streets. This is because loop streets discourage through traffic, and no through traffic of any kind is possible in culs-de-sac, whereas every street in a conventional grid network has the potential to attract non-local traffic.

9. Among the various forms of intersections, T-intersections, which are common in planned neighbourhoods of all types, are generally the safest. This is because the number of

potential conflict points is minimized at T-intersections, as was illustrated in Section 2.3.1.2.

10. Pedestrian accident rate is negatively correlated with footpath density. This is based on the assumption that the more footpaths are provided, the fewer pedestrians who should walk along streets, thus reducing the potential for conflict between pedestrians and vehicles. This hypothesis complements hypothesis 4 to examine the relative safety effects of the modified-Radburn neighbourhoods and the cluster-plan neighbourhoods. Since footpaths most often link dwelling clusters to parks, playgrounds and schools in superblocks, they are more likely to be used by children than other age groups to walk to their most frequented destinations. It is therefore expected that separate footpaths should at least reduce the accident rates of school-age children, if not those of other age groups or neighbourhood populations as a whole.

4.1.3 Hypotheses Relating to Variations in Local Environmental Configuration

While certain street patterns are assumed to be more hazardous for pedestrians, it should not be expected that all streets or intersections of the same form will be equally significant accident locations. In other words, although neighbourhoods of the same type are configured with similar street patterns, it does not follow that their pedestrian accident rates will be identical. This is because pedestrian accidents cannot be attributed solely to street layouts and forms, but must also relate to the intensity of vehicular traffic and pedestrian flows on different streets, which is influenced in turn by the spatial arrangement of vehicular and pedestrian traffic generators. As was described in Chapter 3, Edmonton's neighbourhoods exhibit variations in their environmental configuration not only between types, but also within types, since neither unplanned nor planned neighbourhoods were developed with identical forms. These variations may have different safety effects on pedestrians, and they might also contribute to the variations in pedestrian safety among different types of neighbourhoods. Since land use patterns commonly vary more among neighbourhoods of the same types, in comparison with other design elements, they are treated here as particularly important features of local configuration. On the basis of a preliminary examination of the maps of pedestrian accident distribution produced for the thesis research, the following hypotheses are formulated to investigate the associations between the incidence of pedestrian accidents and the local variations in environmental configuration:

11. (a) Grid neighbourhoods that are adjacent to commercial ribbons have higher pedestrian accident rates than those that are not; (b) grid neighbourhoods that are adjacent to apartment strips have higher accident rates than those that are not; (c) grid neighbourhoods with intrusive arterial streets have higher accident rates than those without.

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rates than those that have no incompatible land uses in their close vicinity.

16. While commercial land uses in residential areas tend to generate more pedestrian accidents than other types of land uses, planned shopping centres court fewer pedestrian accidents on adjacent arterial streets than unplanned commercial ribbons do. Accordingly, neighbourhoods adjacent to planned shopping centres have lower pedestrian accident rates than those fronting on commercial ribbons.

The first set of hypotheses are tested in Chapter 6; the second are dealt with in Chapter 7; and the third form the basis for Chapter 8.

4.2 Study Plan

4.2.1 Study Period and Study Area

In general, the longer a study period, the more accurate the results are likely to be, because longer study periods mean larger databases, and larger databases tend to produce more reliable estimates of population characteristics. In the case of pedestrian accidents in Edmonton, although the City Transportation Department has been keeping records for several decades (and these records provided primary information on the safety indicators that are essential for the thesis research), a fixed format for the database was not adopted until 1982. In other words, the pedestrian accident records prior to 1982 are not directly comparable with those for the subsequent years.

The study period had therefore to be limited to the years 1982 to 1990, inclusive. (Data for 1991 and 1992 were not available at the time of writing.) Nevertheless, it is believed that the data for these nine years, which contain 3804 pedestrian accident records altogether, allowed a meaningful examination of the pedestrian safety effects of the residential built environment in Edmonton.

For physical planning purposes, Edmonton's residential areas are divided into 173 separate neighbourhoods by the City's Planning Department, though some of them were developed too recently for meaningful comparisons of their accident records. Hence, only those that came under development before 1982 were included in the research. This reduced the survey population to a total of 153 neighbourhoods, all of which have accident data for the full nine years, 1982-1990.

Since "neighbourhoods", as defined by the Planning Department, were adopted as the areal units for analytical purposes, classification of the study neighbourhoods became a crucial step of the thesis research. The classification scheme, which was established in Chapter 3, comprises the following 5 categories:

(1) grid neighbourhood

(2) modified-grid neighbourhood

(3) independent neighbourhood unit

(4) modified-Radburn neighbourhood forming part of a hierarchical structure

(5) cluster-plan neighbourhood forming part of a hierarchical structure.

However, applying this scheme was not altogether straightforward. The chief difficulty was caused by the modified grids, since modifications to street layout and block pattern vary so greatly that those at the upper extreme are not easily distinguished from true neighbourhood units. Difficulties were also encountered with the differentiation between the modified-Radburn and cluster-plan neighbourhoods. Characteristically, these two types of neighbourhoods are configured with the same general land use patterns, street patterns and block format; their only significant difference is that the modified-Radburn neighbourhoods have separate footpath networks, whereas the cluster-plan neighbourhoods have occasional footpaths only. However, not all modified-Radburn neighbourhoods have equally extensive footpath networks; some, whose physical development spanned the 1970s and early 1980s, have close similarities with the later cluster-plan neighbourhoods. In general, the date of development was sufficient to distinguish them, but some neighbourhoods have a transitional form, identified by occasional footpaths rather than continuous networks in their most recently developed portions.

With these difficulties in mind, the following classification procedures were adopted:

(1) To be classified as modified-grid rather than grid, a neighbourhood had to be have been subject to a replotting

scheme in the 1950s. This determination was based on Dale's thesis on Edmonton's physical development (Dale, 1969), which includes an extensive treatment of replotting activity, and on information from the Edmonton Planning Department, which coined the term "modified-grid" and whose designations were largely accepted. Under this rule, areas of grid subdivision that were modified slightly by redevelopment actions in the 1970s and 1980s continued to be classified as grid neighbourhoods. The Canora neighbourhood, which is illustrated in Figure 3.3 , is a good case in point (Sicoli, 1984).

(2) For those neighbourhoods that had been replotted, if fewer than one-fifth of their total numbers of blocks after replotting were regular conventional blocks (i.e. grid blocks), and if all their boundary streets had been redesigned with either service roads or reversed frontages, they were classified as independent neighbourhood units. The remainder were the modified-grid neighbourhoods as defined for thesis purposes. The distinction was well illustrated in Chapter 3 in the examples of Sherbrooke (Figure 3.4) and Belgravia (Figure 3.5).

(3) By and large, the distinction between independent neighbourhood units and modified-Radburn or cluster-plan neighbourhoods was clear-cut. The only overlap affects some neighbourhoods that were built in the mid to late 1960s, when Edmonton was starting to experiment with community-scale configuration. For thesis purposes, the principle of hier-

archical organization is associated with neighbourhoods of the modified-Radburn and cluster-plan types, but some conventional neighbourhood units also show similar features, notably shopping centres and junior high schools deliberately located for joint access.

(4) The modified-Radburns were differentiated from the cluster-plan neighbourhoods in that they must have separate footpaths in the core superblocks where their major local service facilities are usually situated. This is an essential characteristic of the Radburn concept. If it is missing, it is impossible to connect the various footpaths into a comprehensive neighbourhood network.

On this basis, the 153 study neighbourhoods were distributed as follows:

grid neighbourhoods (type 1): 42

modified-grid neighbourhoods (type 2): 19

independent neighbourhood units (type 3): 37

modified-Radburn neighbourhoods (type 4): 33

cluster-plan neighbourhoods (type 5): 22.

4.2.2 Generation of the Characteristics of Pedestrian Accidents

Although the thesis research focuses on the associations between the incidence of pedestrian accidents and environmental features, it was necessary first to extract some general characteristics of pedestrian accidents from Edmonton's data. These are (1) spatial patterns of pedestrian accident distribution (i.e. pedestrian accidents in residential areas vs. those in non-residential areas); (2) pedestrian accident distribution for different age groups; (3) temporal and seasonal patterns of pedestrian accidents; and (4) accident characteristics in relation to traffic control measures. The general purpose of identifying these characteristics is to establish the validity of the research problem as specified in Section 2.4.

Specifically, these characteristics are expressed with (1) the proportions of pedestrian accidents in residential areas and in non-residential areas, respectively, accompanied by an accident distribution map; (2) the frequencies of pedestrian accidents and pedestrian accident rates for different age groups; (3) the proportions of pedestrian accidents for each hour of the day, each day of the week and each month of the year; and (4) the proportions of pedestrian accidents associated with different forms of traffic control devices. All of these were extracted and tallied from original accident records.

For the thesis purpose, the total population is divided into three major groups: children, adults and the elderly. Children are defined as the age group from 1 to 19 years old; adults are defined as from 20 to 64 years; and the elderly are those 65 and over. Children are further broken down into three sub-groups: (1) pre-schoolers from 0 to 4 years; (2) elementary/junior high-school-aged children from 5 to 14 years; and (3) senior high-school-aged children from 15 to 19 years. The subdivision of children is pertinent because their needs for local service facilities and their general walking behaviour vary; their accident patterns may therefore be different.

4.2.3 Methods for Testing the Hypotheses Relating to General Neighbourhood Form

To test the hypotheses that relate to general neighbourhood form, mean pedestrian accident rates were compared among the five types of neighbourhoods in Edmonton. Two types of rates were used. The first, the gross accident rate, was calculated from all accidents, including those that occurred on the neighbourhood boundary streets. In the second, the intra-neighbourhood pedestrian accident rates, accidents on boundary streets were excluded, so the rates apply only to those accidents that happened inside the neighbourhoods. Their purpose is to test whether neighbourhoods consisting of superblocks and cluster blocks provide safer interiors than those composed of conventional blocks (Hypothesis 5). Hypotheses 1-4 were tested using gross pedestrian accident rates. In all cases, the tests were performed first for total neighbourhood population and then for the age groups defined above. The intention of breaking total neighbourhood population down is to discover whether the "safer" forms of residential environment benefit all segments of the neighbourhood population, especially children and elderly people.

Since the safety effects of neighbourhood forms are the focus of interest, potentially confounding factors must be controlled as much as possible. Variations in population density and traffic volume are of particular concern, because large numbers of people and heavy traffic translate into a high potential for pedestrian-vehicle conflict. The first of these factors can be dealt with effectively by the use of a pedestrian accident rate, expressed as the number of pedestrian accidents per 1,000 neighbourhood population, but the second is more problematic. For many years, Edmonton Transportation has been counting traffic volumes on the city's main roads (mostly arterial streets), but not on low-level residential streets, which means that there is insufficient information for an accurate control of the effects of traffic volume. Nonetheless, it can be assumed that the internal vehicular traffic in a neighbourhood is mainly generated by its residents. That is, the traffic volume of a neighbourhood is positively correlated with its population size and density. Under this assumption, the use of pedestrian accident rates can be regarded as partially reducing the uneven effects of traffic volumes in different residential neighbourhoods. Any other variations in traffic volumes (such as through traffic in the interiors of neighbourhoods and excessive traffic on neighbourhood boundary streets) that are not accounted for by the use of pedestrian accident rates, are regarded as being caused by differences in environmental forms. This is one of the environmental problems to be investigated in the thesis research.

Pedestrian accident rates were compared using the ANOVA (analysis of variance) technique. This is used to compare more than two sample means based on interval or ratio data, and involves the calculation of two types of variance: within-category variance and between-category variance. The two types of variance form an F-test. In the research problem, there are five categories, which are the five types of neighbourhoods. The variables used in the ANOVA analysis are shown in Table 4.1, where $x_{1,n}$, $x_{2,n}$, $x_{3,n}$, $x_{4,n}$ and $x_{5,n}$ represent either gross or intra-neighbourhood pedestrian accident rates for individual neighbourhoods of each of the five types; and $\bar{x}_1$, $\bar{x}_2$, $\bar{x}_3$, $\bar{x}_4$ and $\bar{x}_5$ are the mean gross or intra-neighbourhood pedestrian accident rates for the five neighbourhood types, respectively.

Table 4.1
Tabulated variables for the analysis of variance

Neighbourhood type	1	2	3	4	5
Pedestrian accident rate for each neighbourhood	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$	$x_{4,1}$	$x_{5,1}$
	$x_{1,2}$	$x_{2,2}$	$x_{3,2}$	$x_{4,2}$	$x_{5,2}$
	..	..	..	..	..
	..	..	..	..	..
	$x_{1,n}$	$x_{2,n}$	$x_{3,n}$	$x_{4,n}$	$x_{5,n}$
Type mean	$\bar{x}_1$	$\bar{x}_2$	$\bar{x}_3$	$\bar{x}_4$	$\bar{x}_5$

In the particular procedure, the statistical hypotheses are:

H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ (i.e. there is no variation in terms of gross pedestrian accident rate among the five neighbourhood types),

H_1: at least two of the means are unequal.

Whether to accept or reject H_0 will depend on the calculated F-value (i.e. the ratio of between-category variance and within-category variance). If the calculated F-ratio is greater than the critical F-ratio found in a standard F-table with the same degrees of freedom, we reject H_0 and accept H_1; otherwise, we do not reject H_0.

If the five means are found to be statistically different, the next step is to rank them using the technique of Two-Sample Difference-of-Means Test. The general hypothesis for the expected rank is the following:

$\bar{X}_1>\bar{X}_2>\bar{X}_3>\bar{X}_5>\bar{X}_4$

That is, grid subdivisions have the highest mean pedestrian accident rates, both gross and intra-neighbourhood; modified-grid neighbourhoods have the second highest mean rates; the independent neighbourhood units have mean rates that are lower than those for grid and modified-grid neighbourhoods, but higher than the mean rates for the neighbourhoods of hierarchical organization. Between the modified-Radburn neighbourhoods (type 4) and the cluster-plan neighbourhoods (type 5), the former with separate footpaths have lower mean accident rates than the latter.

In the procedure of Two-Sample Difference-of-Means Test, two means were compared at a time. For example, the first pair of statistical hypotheses is stated as the following:

H_0: $\bar{X}_1-\bar{X}_2\leq 0$

H_1: $\bar{X}_1-\bar{X}_2>0$

The two means to be compared form a t-test. If the calculated t-value is greater than the critical t-value found in a standard t-table with the same degrees of freedom, we reject H_0 and accept H_1. Otherwise, we do not reject H_0. In the thesis, this procedure was repeated until all five neighbourhood types were ranked for their mean pedestrian accident rates. Both tasks, ANOVA and the Two-Sample Difference-of-Means Test, were performed using the computer program STATGRAPHICS.

4.2.4 Methods for Testing the Hypotheses Relating to Circulation Networks

Comparing pedestrian accident rates among different forms of residential environments at the neighbourhood level does not explicitly reveal how pedestrian accidents are related to street patterns and separate footpath networks, two design elements that are critical to environmental configuration. This section describes how their relations were investigated. These analyses provide partial explanations for the variations in pedestrian accident rates among different types of neighbourhoods.

4.2.4.1 Correlation Analyses between Pedestrian Accident Rates and Street Density, Intersection Density, and the Number of Neighbourhood Entrances/Exits

The hypothesis that pedestrian accident rates are positively correlated with street density, intersection density and the number of neighbourhood entrances/exits (i.e. Hypothesis 6) was tested using the technique of correlation analysis. The variables for the correlation analysis are tabulated in Table 4.2.

Table 4.2
Tabulated variables for correlation analysis

Individual neigh-bourhood	Number of accidents per 1,000 people	Number of intersec-tions per 100 ha.	Length of street per 100 ha.	Number of entry points per neigh-bourhood
1	y_1	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$
2	y_2	$x_{1,2}$	$x_{2,2}$	$x_{3,2}$
.	..	...	...	...
.	..	...	...	...
n	y_n	$x_{1,n}$	$x_{2,n}$	$x_{3,n}$

A general correlation analysis was performed first to show bivariate associations, in which pedestrian accident rate is correlated with one environmental variable at a time. Because street density, intersection density and the number of neighbourhood entrances/exits should be correlated with one another to some extent, the correlation of any one variable with accident rates, when the other two are not controlled, is actually a combination of the effects of all three. For this reason, a partial correlation analysis was also conducted to verify if the relative importance of the three environmental factors established in the general correlation holds true when the confounding effects between them are controlled.

4.2.4.2 Examination of the Relations between Pedestrian Accidents and the Type of Street and Intersection

Streets in residential areas are functionally classified as arterial streets, collector streets, and access streets. They are normally designed to have different carrying capacities and speed limits. In terms of neighbourhood unit theory, residential streets can also be differentiated as boundary streets and internal streets. For the particular purpose of the thesis study, the following street classification was adopted:

(1) neighbourhood boundary street

(2) internal collector street

(3) straight access street

(4) short-loop access street

(5) cul-de-sac access street

(6) lanes and service roads

To each pedestrian accident record in the database was added a new variable for street type according to the location where it occurred. This was done by first plotting the accidents on large-scale maps, and then identifying the type of street associated with each accident. The proportions of pedestrian accidents in each category of street were calculated and compared among different neighbourhood types. This provided the test for the hypothesis that most pedestrian accidents happen on neighbourhood boundary streets; that the boundary streets of grid neighbourhoods are the most hazardous for pedestrians; and that the proportion of pedestrian accidents on boundary streets is higher for independent neighbourhood units than it is in areas of hierarchical organization. It was also the means for determining whether the cul-de-sac is the safest form of access street for pedestrians, and if short-loop streets are safer than straight access streets.

To determine if T-intersections are safer than other forms of intersections, all pedestrian accidents that happened at intersections were singled out for analysis. Each accident was assigned a variable for intersection type (i.e. T-intersection, cross-intersection, acute-intersection, and traffic circle). The variable for intersection type was then analyzed using the method of cross-tabulation, to see whether some types of intersections court more pedestrian accidents than others.

4.2.4.3 Investigation of the Relations between Pedestrian Accidents and Separate Footpath Networks

This investigation consisted of two parts. The first part was a correlation analysis between pedestrian accident rates and footpath density; the second part investigated accident locations in relation to footpath networks. The analysis was limited to type 4 neighbourhoods since they are the only ones with footpath networks.

Separate footpaths have been claimed to be the safest type of pedestrian facility in residential areas. In Section 4.2.3, it was described how the pedestrian accident rates for different types of neighbourhoods were compared using ANOVA and Two-Sample Difference-of-Means Test, from which it should be possible to find out if neighbourhoods with separated footpaths (i.e. type 4) are the safest in general. To obtain further evidence about the contribution that separated footpaths make to pedestrian accident rates, a correlation analysis using the density of footpaths and pedestrian accident rates was conducted. The density of footpaths was expressed as the length of footpaths (in meters) per hectare. The two variables for the correlation analysis are tabulated in Table 4.3. Pearson's product-moment correlation coefficient "r" was calculated, to determine whether separate footpaths correlate negatively with pedestrian accident rates.

As the second part of this investigation, the locations of all 235 pedestrian accidents in type 4 neighbourhoods were examined on airphotos, to see where they occurred in relation to the footpath networks. Since all footpaths cross streets at grade, they create more "intersections", or conflict points,

Table 4.3
Tabulated variables for correlation analysis between separated pedestrian paths and pedestrian accident rates

Neighbourhood	Number of accidents per 1,000 people	Length of footpaths (m) per hectare
1	Y_1	X_1
2	Y_2	X_2
...	...	...
...	...	...
n	Y_n	X_n

on boundary and collector streets. This part of the investigation aimed to discover if more accidents happened near the junctions of footpaths and streets than at other mid-block locations, thus reducing the overall safety effects of the footpath networks.

4.2.5 Methods for Testing the Hypotheses Relating to Variations in Local Environmental Configuration

To substantiate the postulated associations between pedestrian accidents and variations in local environmental configuration (i.e. to test hypotheses 11 to 16), a table comprising pedestrian accident rates, accident frequencies and a "checklist" of critical environmental features was compiled for each neighbourhood type. These tables were designed to show whether the critical environmental features are indeed closely associated with the neighbourhoods that have relatively high pedestrian accident rates. The various types of neighbourhoods were analyzed separately to overcome the confounding effects of their differing street patterns. The analyses were then complemented by detailed area studies to demonstrate relations between the incidence of pedestrian accidents and the critical environmental features at a micro scale. At this stage, pedestrian accident frequencies are useful in indicating actual concentrations of accidents in the study neighbourhoods closely associated with the critical environmental features.

To compare the safety effects of different sections of arterial streets in consideration of their adjacent land use patterns (especially commercial and apartment ribbons and streets surrounding district and regional shopping centres), an index of pedestrian accident density was developed. This is expressed as the number of accidents per 10,000 daily vehicles (an average weekday) per 100 metres. Such an index can control the effects of the variations in traffic volume on different sections of arterial streets, thereby isolating the safety implications of the adjacent land use features.

4.3 Data Sources

Three broad types of information were used to carry out the research plan. The first is pedestrian accident records used as safety indicators; the second is demographic data used for the calculation of pedestrian accident rates for individual neighbourhoods; and the third is environmental information used to identify different types of neighbourhoods for the thesis research, and to interpret the associations between the incidence of pedestrian accidents and the various features of environmental configuration. This section describes all the data sources.

4.3.1 Pedestrian Accident Records

There are three possible criteria for assessing traffic safety in residential areas: the number of real accidents; the number of near accidents; and the perception of danger on streets (OECD, 1979). The first set can be called hard data because they are often officially recorded. The second and the third can be called soft data, since there are no formal records for them. Hard data form the basic indicators of road safety. As Marks (1957:325) remarked, "The principal symptom of poor design is the history of excessive traffic accidents". If soft data are available, they can help explain safety problems, but they are very difficult to collect. Hence, only hard data were used for the thesis research.

Pedestrian accident data for Edmonton are kept by two civic departments: the Police Department and the Transportation Department. The most important difference between them is that the police records contain the names and addresses of the pedestrians and drivers involved in the accidents; the Transportation Department's records do not include this confidential information and so are accessible to the public. For this reason, only the records kept by Edmonton Transportation were used for the thesis research.

The original database contains 3,804 pedestrian accident records for the period 1982-1990; all happened on public streets and caused either bodily injury or death for the pedestrians involved. (There are no records for those accidents that caused neither injury nor death.) Each record includes 21 variables (see Table 4.4), covering the following types of information:

——location of the accident by street and avenue

——date and time of the accident

Table 4.4
Variables in the pedestrian accident records for Edmonton

1. report number
2. location by street and avenue
3. avenue/street portion
4. time of day
5. day of week
6. date and month
7. property damage
8. surface condition
9. driver's age
10. driver's sex
11. driver's pre-accident manoeuvre (movement)
12. driver's human action (response to the operation)
13. driver's travel direction
14. the driving lane the driver was in
15. pedestrian's age
16. pedestrian's sex
17. pedestrian's pre-accident manoeuvre
18. pedestrian's human action
19. pedestrian's travel direction
20. accident class (severity of injuries)
21. traffic control

Source: Edmonton Transportation Department, <u>Pedestrian Accident Records</u>, 1982-1990

——age and sex of the pedestrian/driver involved in the accident

——traffic control measures at the accident location

——pre-accident manoeuvres and human actions of both the pedestrian and the driver

——surface condition of the road when the accident occurred

——severity of injuries and property damage.

As can be seen, the database is rich in information for the thesis research. For example, the variable "location by street and avenue" was used to map the spatial patterns of accidents; variable 3, "avenue/street portion", was used to determine if an accident happened at an intersection or in mid-block; variables for time, day, date and month allowed temporal and seasonal patterns of pedestrian accidents to be generated; and "pedestrian's age" facilitated the calculation of accident rates for different age groups. On the other hand, this database does not specify the types of neighbourhoods, streets and intersections where each accident happened. This is key information for thesis purposes, so four new variables were generated for each pedestrian accident record:

(1) the type of neighbourhood in which the accident occurred (accidents on boundary streets were assigned to the neighbourhoods to the right according to the driver's travel direction)

(2) the type of street on which the accident occurred

(3) the type of intersection at which the accident occurred

(4) the UTM coordinates for each accident location (for computer-aided mapping).

The new variables were obtained by first plotting all the pedestrian accidents on a large-scale map with neighbourhood boundaries and street patterns, according to street/avenue locations, then identifying the associated neighbourhood and street/intersection types for each pedestrian accident, and digitizing all the accidents by their locations.

4.3.2 Demographic Data

To calculate pedestrian accident rates for comparative analysis, the population of each study neighbourhood needs to be known. This information was derived from Edmonton civic census data. In the study period, the City of Edmonton conducted censuses in 1982, 1983, 1986, 1987, 1989 and 1990. The data are summarized at three scales (census tract, subtract and enumeration area) and are broken down for five-year-age groups (0-4, 5-9, 10-14, 15-19, etc.). The summaries for enumeration areas are the most useful for the thesis purpose. Since neighbourhood boundaries coincid with enumeration area boundaries, it is possible to calculate neighbourhood populations by aggregating the appropriate enumeration areas. In addition, in consideration of the fact that the study period covers nine years and the demographic profiles of individual neighbourhoods might change considerably over that time, average neighbourhood populations for the study period were calculated, based on the censuses of 1983, 1986 and 1989. These divide the study period with minimum intervals, so the averages derived from them should be close to the true populations of the study neighbourhoods for the study period, bearing in mind that censuses were not conducted in 1984, 1985 and 1988.

4.3.3 Environmental Information

Environmental information was derived from maps, air-photos, documents produced by different civic departments of the City of Edmonton, and fieldwork.

1. Neighbourhood Fact Sheets

All 153 neighbourhoods are covered by neighbourhood fact sheets, which Edmonton's Planning and Development Department first prepared in 1983 and began to update in 1987. They were used mainly as the basis for classifying the study neighbourhoods. Of greatest importance, each fact sheet includes a map showing current land use and the physical configuration of streets, blocks and footpaths (where they occur). Unfortunately, however, the maps were not produced on a uniform scale and their scales are not indicated. Consequently, they were not suitable for the generation of such environmental variables as street density, intersection density and footpath density.

2. **Neighbourhood Boundary Map**

This map at the scale of 1:30,000 was produced by the Planning and Development Department in 1986. It shows street networks, and divides the residential areas of Edmonton into 173 individual neighbourhoods. The neighbourhood boundaries are exactly the same as those used for the neighbourhood fact sheets, so this map could be used to identify the basic units for classifying residential environments. Most importantly for thesis purposes, the following environmental variables were generated from this map:

(1) total area of each neighbourhood

(2) total length of streets in each neighbourhood

(3) total number of intersections in each neighbourhood

(4) total number of entrances/exits for each neighbourhood.

These variables were used to create indices for the correlation analyses and for the analysis of variance.

3. **Airphotos**

Edmonton Public Works takes airphotos of the Edmonton area every two years. The most useful ones are at 1:5000 scale because streets, driving lanes, footpaths, blocks, buildings, and open spaces are clearly visible and distinguishable. These photos were used for the interpretation of pedestrian accident patterns in relation to adjacent environmental features, as well as for the measurement of the total length of separated footpaths in each of the type 4 neighbourhoods.

4. Transportation System Map

This map was produced by the Transportation Department as Appendix "A" to Transportation System Bylaw Number 9368 of the City of Edmonton, in which the official designation of arterial streets, collector streets and residential access streets is represented. This designation was used without modification to classify Edmonton's residential streets for thesis purposes.

5. Traffic Flow Maps

The Transportation Department produces a traffic flow map for Edmonton every year. Although these maps show the average weekday traffic volumes on designated arterial streets only, they still provide useful information for the thesis study. They were used in the interpretation of the spatial patterns of pedestrian accident distribution, especially on neighbourhood boundary streets.

6. Digital Data Files of Transportation Network and Neighbourhood Boundaries

The digital data file of Edmonton's transportation network was prepared by the Public Works Department. The digital file of neighbourhood boundaries was generated by the Planning and Development Department. Both files were used with the pedestrian accident records to generate pedestrian accident distribution maps.

7. Fieldwork

Fieldwork was conducted in the neighbourhoods with relatively high accident rates, to observe those local environmental features that are not shown on land use maps and cannot be seen clearly on airphotos, but have effects on pedestrian safety. These include: (1) street form (i.e. with or without reversed frontage); (2) form of sidewalks (with or without planting buffers); and (3) availability and type of pedestrian facilities around major pedestrian generators (such as shopping centres and schools). In addition, limited observations of actual pedestrian behaviour were made at a few locations where obvious accident clusters stand out on pedestrian accident distribution maps. The purpose of the observations was to find out if pedestrians (especially children) who are crossing streets actually use the facilities that have been provided. These observations were useful for explaining the accident patterns at these specific locations, but general conclusions about pedestrian behaviour may not be valid because the observations were not conducted with a systematic procedure.

CHAPTER 5

CHARACTERISTICS OF PEDESTRIAN ACCIDENTS IN EDMONTON

In this chapter some general characteristics of pedestrian accidents in Edmonton are extracted from the data base provided by the City Transportation Department. Specifically, the following are analysed: (1) spatial patterns of pedestrian accidents within Edmonton; (2) pedestrian accident distribution in relation to different population groups; (3) temporal and seasonal patterns of pedestrian accidents; and (4) characteristics of pedestrian accidents in relation to traffic control measures. The overall purpose of these analyses is to establish that the research problem is well-founded and that there is evidence to substantiate the need for the investigation as it was envisaged in Chapter 4. Individually, the separate analyses were designed with the following ends in view. First, to demonstrate that pedestrian accidents are a salient problem in Edmonton's residential areas and that the study of residential planning and design for pedestrian safety is therefore pertinent. Second, to generate local evidence that children and elderly people are particularly vulnerable to pedestrian accidents (as revealed by studies done in European and other North American cities) and should receive special attention in the thesis study. The analysis should also indicate whether most pedestrian accidents involving school-aged children were likely to be related to their school trips, an assumed problem that planners have long aimed to overcome through their environmental solutions. Third, to find if winter-related road conditions, as Hillman and Whalley (1979) suggested, are a significant factor in pedestrian accidents in Edmonton, thus reducing the possible importance of the built environment and environmental solutions. This is particularly relevant to Edmonton, where the winter is as long as 4-5 months, during which time streets are often covered by snow and ice. Finally, to determine whether regulatory measures are sufficient on their own to resolve the problem of pedestrian accident risk in residential areas, so rendering environmental solutions unnecessary.

5.1 Spatial Patterns of Pedestrian Accident Distribution within Edmonton

In the nine-year period, 1982 to 1990, 3804 pedestrian accidents, including 119 fatalities, were recorded for the whole of Edmonton by the City's Transportation Department (Table 5.1). The annual totals fluctuated around 400, giving

Table 5.1
Pedestrian accidents in Edmonton, 1982-1990

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	Total
Injuries	405	370	417	423	381	439	414	428	408	3685
Fatalities	15	8	10	10	10	14	17	24	11	119
Total	420	378	427	433	391	453	431	452	419	3804

an average of 1.2 accidents per day. More importantly, for thesis purposes, 80 per cent (or 3034) of the accidents occurred in areas defined here as residential.

Figure 5.1 shows the spatial distribution of all 3804 pedestrian accidents. It can be seen that the majority of those that occurred in non-residential areas are concentrated in the downtown and Boyle Street districts. This is not surprising. The downtown area has the city's highest densities of both pedestrian and vehicular traffic all year round (Wang, 1988), while the Boyle Street district contains many ethnic institutions, as well as a large number of low-quality shops and services, such as low-rent hotels, thrift stores, pawnshops, and vacant sites used as parking lots. As Edmonton's "skid row", it draws drug-, alcohol- and prostitute-related transients who are especially prone to pedestrian accidents. Since this district has experienced a fundamental change from its original residential function, it is defined as non-residential in the thesis.

The 3034 pedestrian accidents in residential areas are widely but unevenly spread over Edmonton's 173 neighbourhoods. As Table 5.2 demonstrates, the average was 18 accidents per neighbourhood, but the standard deviation is as high as 25, with the minimum and maximum being 0 and 156 respectively. This uneven distribution of pedestrian accidents in Edmonton's residential areas certainly merits closer investigation.

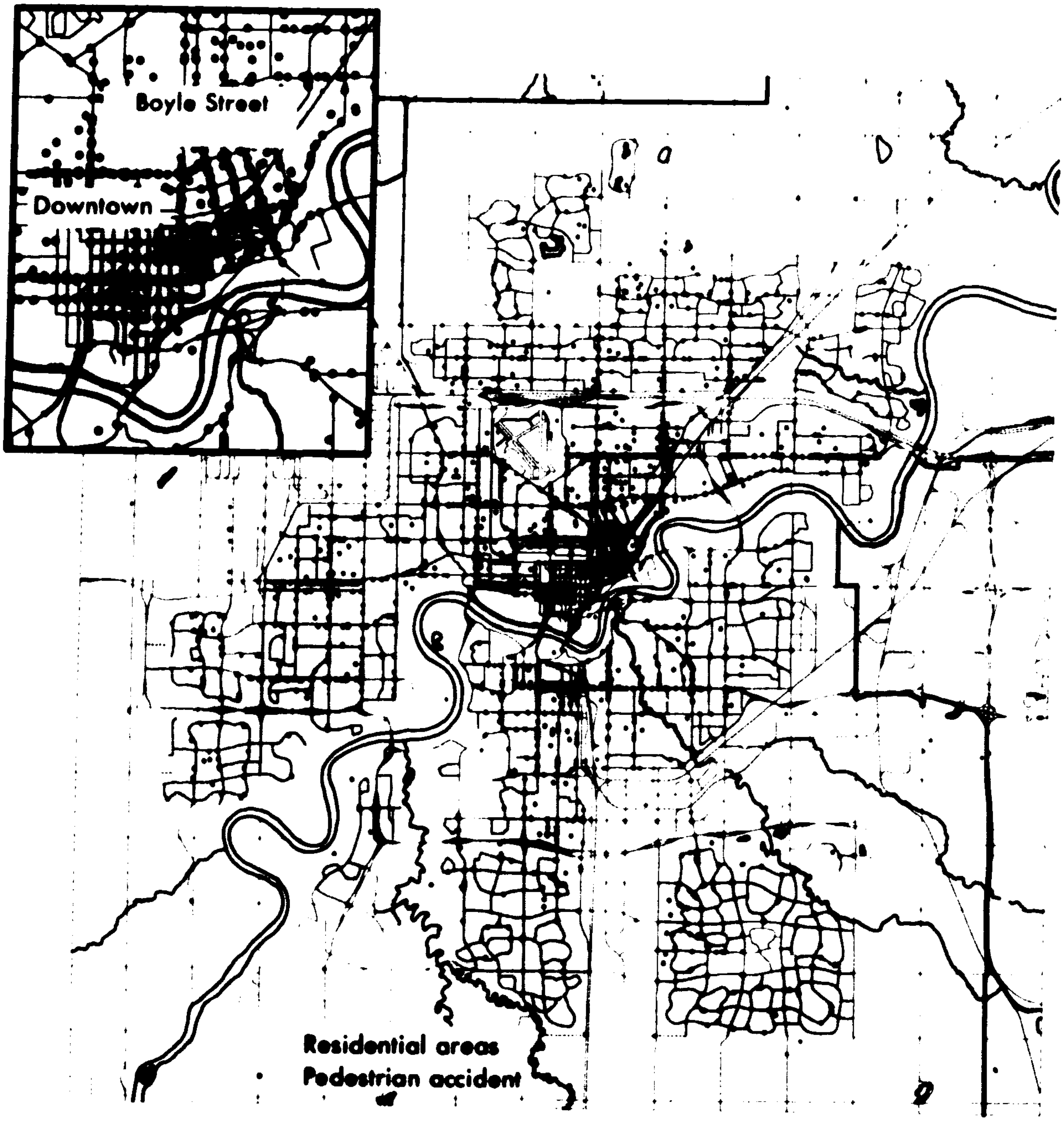


Figure 5.1 Pedestrian accident distribution in Edmonton 1982-1990

Table 5.2
Summary statistics for the pedestrian accident distribution in Edmonton's residential areas, 1982-1990

Total number of neighbourhoods	173
Average number of accidents	18
Standard deviation	25
Minimum number of accidents	0
Maximum number of accidents	156
Range	156

5.2 Pedestrian Accident Distribution in Relation to Different Age Groups

Many studies have found that while accidents happen to pedestrians of all ages, children and the elderly are particularly vulnerable (see Section 2.2.2 in Chapter 2). This section demonstrates that this pattern holds true in Edmonton as well.

Figure 5.2 shows the numbers of pedestrian accidents for the different age groups in Edmonton. While no age group is immune from pedestrian accidents, the highest numbers of accidents are associated with the groups from 5 to 24 years. As age increases, the number of pedestrian accidents generally decreases, with the oldest groups accounting for comparatively small numbers. The number of accidents involving pre-school-age children is also relatively small.

Since the frequency of pedestrian accidents should be a function of the number of people who walk on streets, and the different age groups vary considerably in size, the pedestrian accident rate, expressed as the number of accidents for each 1,000 people of a particular age group, should provide a

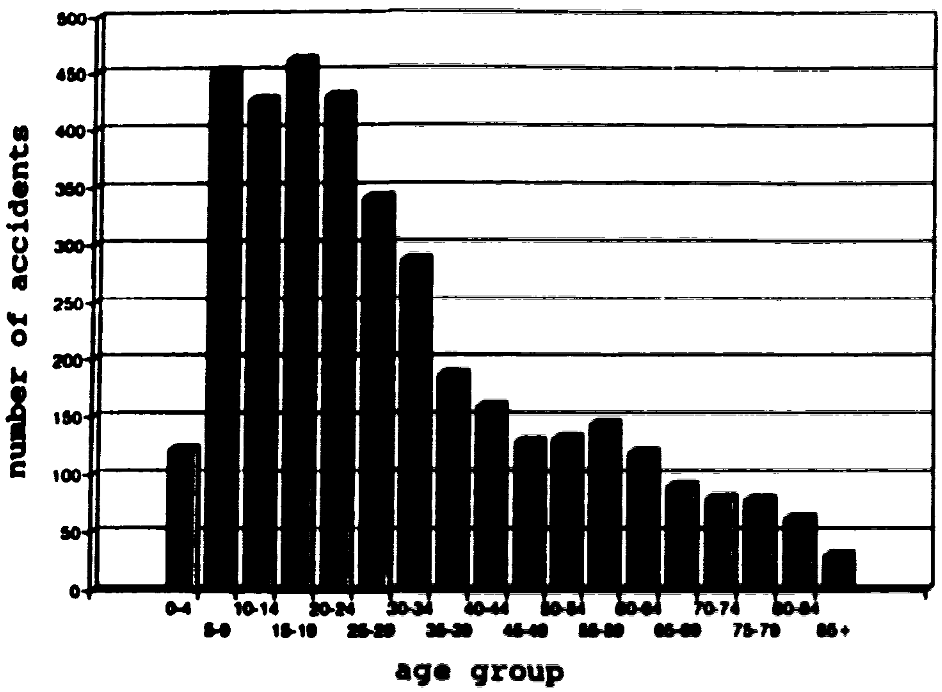
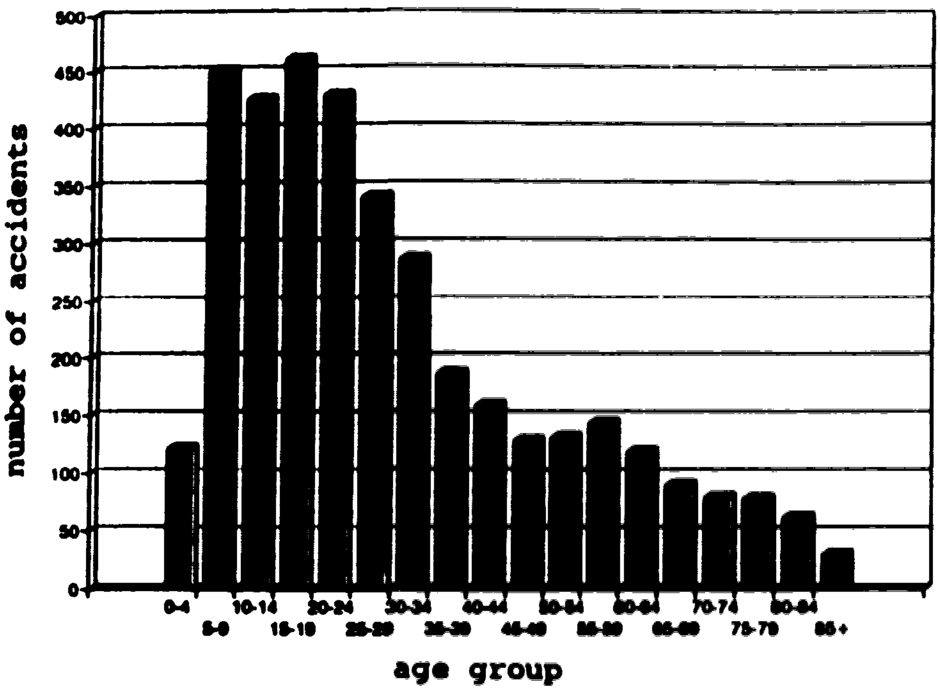


Figure 5.2 Pedestrian accident frequencies for different age groups, Edmonton, 1982-1990



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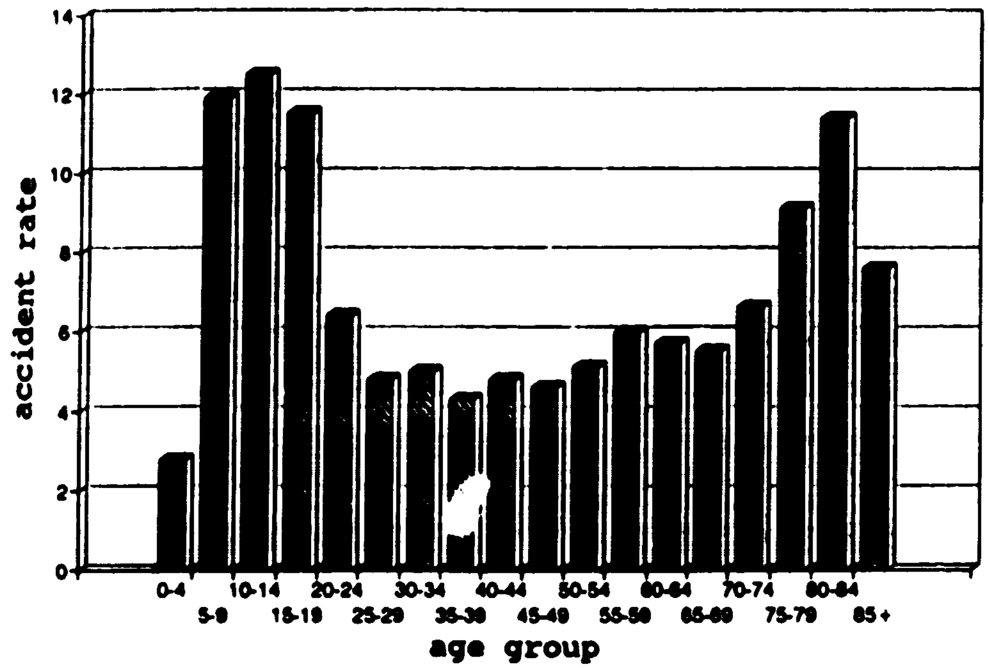

Figure 5.3 Pedestrian accident rates for different age groups Edmonton, 1982-1990

Table 5.3
Pedestrian accidents for different age groups in relation to accident causes, Edmonton, 1982-1990 (in percentages)

Type of cause	Children			Adults	Elderly
	0-4	5-14	15-19		
Pedestrian error	73	57	39	35	22
Driver error	25	40	51	55	70
Others	2	3	10	11	8
Total	100	100	100	100	100

Table 5.4
Pedestrian accidents for different age groups in relation to pedestrian actions prior to the accidents, Edmonton, 1983-1990* (in percentages)

Action	Children			Adults	Elderly
	0-4	5-14	15-19		
Crossing street with ROW	21	42	50	54	69
Crossing street without ROW	33	35	27	25	20
Walking on street	3	2	6	6	2
Running onto street	18	12	5	3	2
Walking on sidewalk	3	1	5	6	4
Emerging from behind autos	20	8	3	3	1
Others/unknown	2	1	4	3	2
Total	100	100	100	100	100

* Data in this table are for the years 1983 to 1990 because the variable of Pre-Accident Pedestrian Manoeuvre in 1982 is not comparable with subsequent years)

children of 0-4, and 35 per cent of the pedestrian accidents involving children of 5-14, resulted from "crossing street without right-of-way", compared with 27 per cent for the youngsters of 15-19, 25 per cent for adults and 20 per cent for elderly people;

(2) 18 per cent of the pedestrian accidents involving children of 0-4 and 12 per cent of the pedestrian accidents involving children of 5-14, were caused by "running onto roadway", compared with 5 per cent for the youngsters of 15-19, 3 per cent for adults and 2 per cent for elderly people;

(3) 20 per cent of the pedestrian accidents involving children of 0-4 and 8 per cent of the pedestrian accidents involving children of 5-14, were due to "emerging from behind/in front of vehicles" (i.e. dart-out), compared with 3 per cent for the youngsters of 15-19, 3 per cent for adults and 1 per cent for elderly people.

Taken together, these data imply that children of 14 and younger are vulnerable to pedestrian accidents largely because they have a much weaker sense of traffic rules than older children, adults and the elderly, and that regulatory measures alone would not be sufficient to ensure their safety. Environmental solutions are desirable as well, to limit the situations where young pedestrians might put themselves at risk.

Although elderly people seem to be the most cautious group (i.e. they commit fewer errors when crossing streets, as Tables 5.3 and 5.4 indicate), there is another piece of evidence (in addition to their relatively high accident rates) that reveals that they are nonetheless exposed to special risk. This is presented in Table 5.5 which demonstrates that elderly pedestrians have the highest proportion of fatal accidents, with 9.7 deaths per 100 accidents, or 3 to 9 times

Table 5.5
Proportion of fatal pedestrian accidents for different age groups, Edmonton, 1982-1990

Age group	Number of deaths per 100 accidents
Children	
0-4	3.3
5-14	1.1
15-19	1.5
Adults	3.2
Elderly	9.7

higher than the proportions of fatal accidents for other age groups. This result also matches the finding reported by the American Automobile Association (1965a), as mentioned in Chapter 2.

5.3 Temporal and Seasonal Patterns of Pedestrian Accident Distribution

Theoretically, the temporal distribution of pedestrian accidents should be consistent with the patterns of vehicular traffic and pedestrian activities. In terms of vehicular traffic, the journey to work is the most regular of all vehicular trips in the city. The highest numbers of work trips are generated during the morning and afternoon rush hours between 07:00 and 08:30 hours and between 16:00 and 18:00 hours. Other trips (including shopping and social trips) usually occur between the peak hours of work trips. Figure 5.4 shows the total vehicular trips on an average weekday in Edmonton, with the highest traffic volumes occurring during

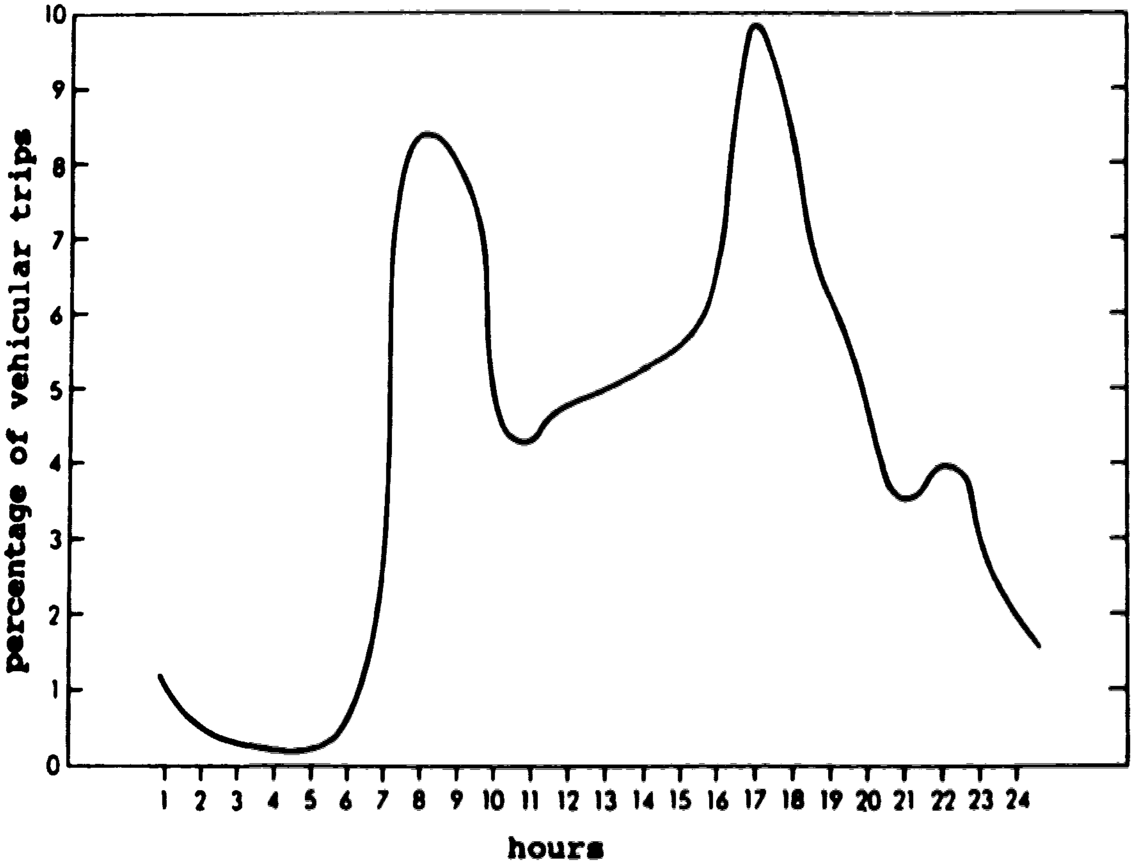

Figure 5.4 Temporal distribution of vehicular traffic in Edmonton,

Source: Edmonton Transportation Department, 1989 the afternoon rush hours. There are no data available for the temporal distribution of pedestrian trips in Edmonton, but it is reasonable to assume that it resembles the temporal distribution of vehicular traffic. For example, pedestrian journeys to and from school and walking trips to and from work, all being necessary and regular trips, mostly take place in the morning between 08:00 and 09:00 hours, and in the afternoon from 15:30 to 18:00 hours. Presumably, the temporal coincidence of vehicular-trip peaks and pedestrian-trip peaks should intensify the conflicts between pedestrians and vehicles, and incur a high incidence of pedestrian accidents.

This assumption is explicitly proved by Edmonton's pedestrian accident data. Figure 5.5 presents the temporal distribution of pedestrian accidents for Edmonton. As can be seen, greater numbers of pedestrian accidents occurred during morning and afternoon rush hours, especially during the latter. This pattern is temporally coincident with that of vehicular trips depicted in Figure 5.4, and is consistent with Hillman and Whalley's discovery in their British study (see Figure 2.3). Another peak of pedestrian accidents occurred during lunch hours.

More importantly, different age groups exhibit distinct temporal patterns. First, the accident distribution for all school-aged children (5-19) has three peaks: one is in the morning between 08:00 and 09:00; another is during lunch time between 12:00 and 13:00; the third, and highest, is in the

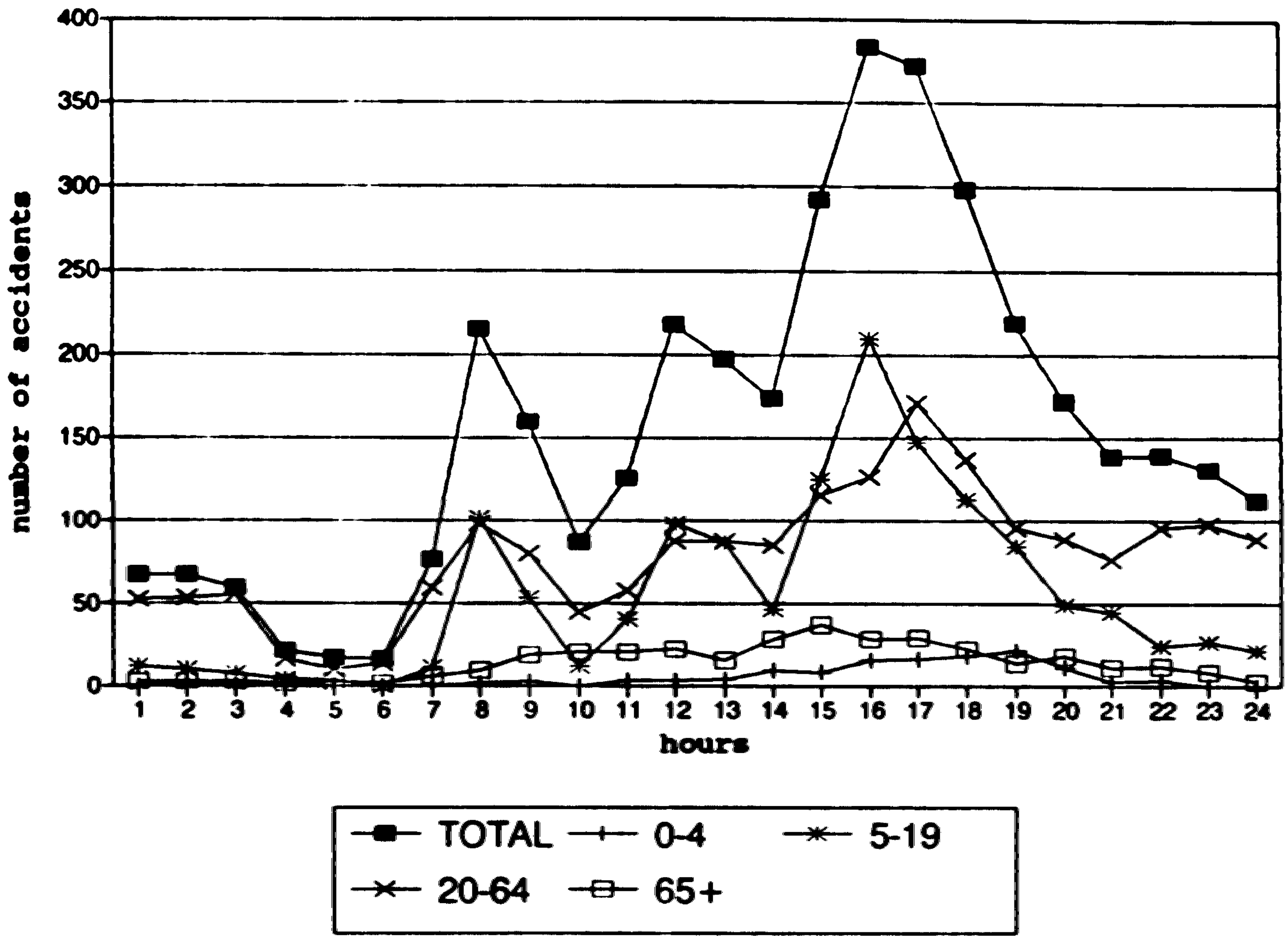

Figure 5.5 Temporal distribution of pedestrian accidents for different age groups, Edmonton, 1982-1990

afternoon between 15:00 and 18:00. These are the hours when school-aged children should be on their way to or from school on weekdays. Two troughs between the three peaks are associated with the hours when students should be in their classrooms.

Second, although the adult accident distribution has similar peaks and troughs, the curve fluctuates less. The morning and afternoon peaks might reasonably relate to people who walk to and from their work (or to transit stops as part of the journey to and from work). The midday peak might be associated with pedestrian trips for other purposes, such as social and shopping trips, including those made by employees on their lunch breaks. The afternoon peak for adult accident distribution falls about one hour behind the afternoon peak of the accident distribution for school-aged children, matching the hours when employed adults should be on their way home from work. Those accidents that occurred later in the evening and during the night mostly involved adults.

Third, the temporal distributions of accidents involving elderly pedestrians and pre-schoolers are rather smooth, without significant peaks. Most accidents involving elderly people happened between 09:00 in the morning and 18:00 in the afternoon. These are the hours when most elderly pedestrians could be expected to make their shopping, social and recreational trips.

The evidence that the incidence of pedestrian accidents is consistent with the patterns of vehicular and pedestrian traffic is supplemented by Figure 5.6, from which it can be seen that the majority of pedestrian accidents happened on weekdays, when most compulsory vehicular and pedestrian trips are made. Fewer pedestrian accidents occurred on Saturdays and Sundays.

Some researchers, such as Hillman and Whalley (1979), suggest that weather is a factor that contributes to the incidence of pedestrian accidents. In other words, there may be more pedestrian accidents in the winter months than in summer because of the greater likelihood of snow and ice on the roads and poor visibility, creating more hazardous conditions for drivers and pedestrians alike. In Edmonton, the four seasons can be broken down as follows: (1) spring: April and May; (2) summer: from June to August; (3) autumn: September and October; and (4) winter: from November to March.

Figure 5.7 shows the seasonal pattern of pedestrian accident distribution for Edmonton. Although there are more pedestrian accidents in December than in any other month, other winter months (November, January, February, and March) do not have more pedestrian accidents than the fall months of September and October. This suggests that winter is not an especially significant factor in the incidence of pedestrian accidents in Edmonton. Table 5.6 reveals a similar finding. During the study period, only 16 per cent of the total pedestrian accidents were related to streets covered by snow

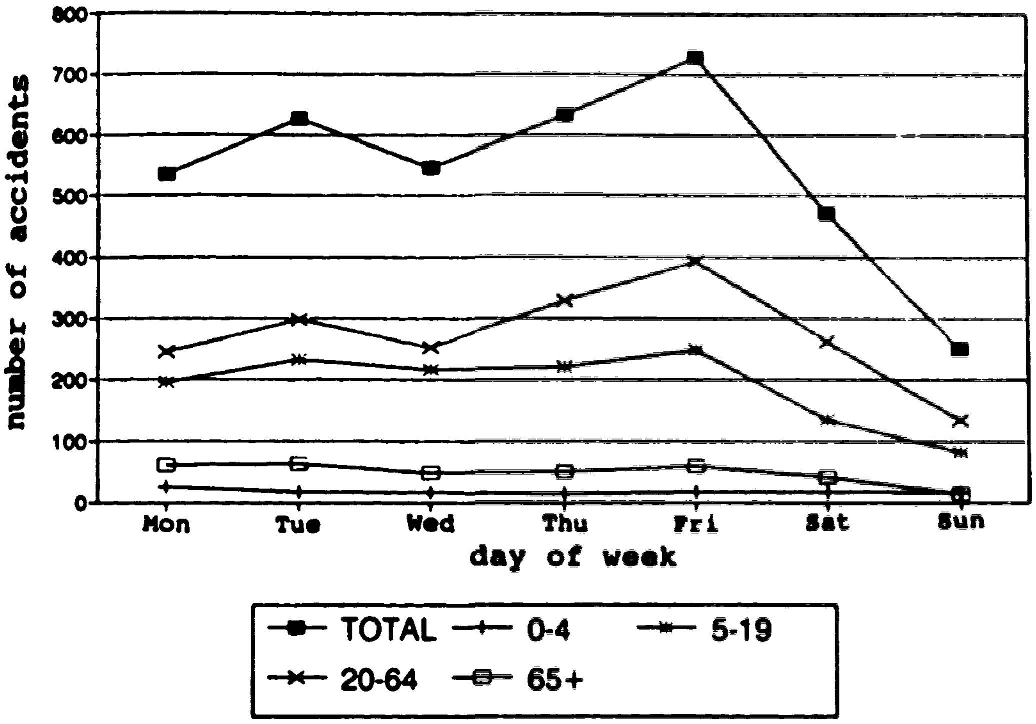

Figure 5.6 Pedestrian accident distribution for different age groups, by day of week, Edmonton, 1982-1990

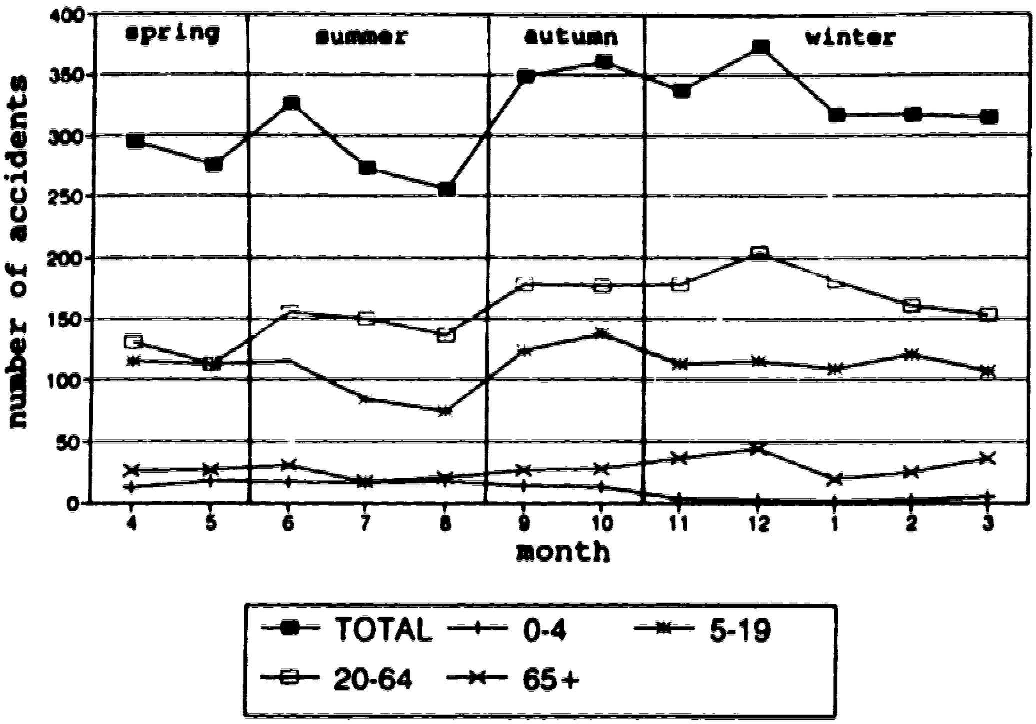

Figure 5.7 Seasonal distribution of pedestrian accidents for different age groups, Edmonton, 1982-1990

Table 5.6
Pedestrian accidents in relation to street surface conditions, Edmonton, 1982-1990

	Dry	Wet	Sandy	Icy	Unknown	Total
Number of accidents	2206	585	44	620	349	3804
Percent of accidents	58	15	1	16	10	100

and ice. Of course, people might walk less in winter months, given Edmonton's severe weather conditions.

Another characteristic of the seasonal pattern is the nearly U-shaped trough over July and August in Figure 5.7 (see the curve for TOTAL), which is mainly caused by the dramatic decrease in the number of accidents involving school-aged children (see the significant depression on the curve for children between 5 and 19). This may be attributed to the summer closure of schools, when students no longer walk to schools regularly on weekdays.

In sum, three general observations can made from the temporal and seasonal patterns of pedestrian accidents in Edmonton. First, pedestrian accidents indeed rise and fall temporally in general consonance with the rise and fall of vehicular journeys and journeys on foot, as Hillman and Whalley (1979) observed in their study in the United Kingdom. This means that there is a strong tendency for pedestrian accidents to occur at times when both vehicular and pedestrian traffic are at high levels and the potential for conflict between them is great. This requires conscious manipulation of the built environment to spatially separate the two kinds of traffic as much as possible, so reducing the potential for conflict. Second, it seems that most pedestrian accidents involving school-aged children were likely to be related to their school journeys. This suggests that in addition to their weak sense of traffic rules, children are particularly vulnerable to pedestrian accidents because many of them have to make regular walking trips to and from school five days a week and ten months a year. Third, there is reasonable evidence from Edmonton's data that winter-related road conditions are not a significant factor in pedestrian accidents; Hillman and Whalley's interpretation is therefore called into question in the Edmonton situation.

5.4 Characteristics of Pedestrian Accidents in Relation to Traffic Control Measures

Since most pedestrian accidents occur when pedestrians cross streets, crosswalks are regarded as critical facilities for the enhancement of pedestrian safety. Physically, there are two broad types of crosswalks: grade-separated crosswalks and at-grade crosswalks. Grade-separated crosswalks, if used, should be absolutely safe from accidents because they completely separate pedestrians from vehicles. In the residential areas of Edmonton, however, grade-separated crosswalks are very rare. At-grade crossings are the norm, and these, strictly speaking, are not design features. They are simply raffic as much as possible, so reducing the potential for onflict. Second, it seems that most pedestrian accidents nvolving school-aged children were likely to be related to heir school journeys. This suggests that in addition to their eak sense of traffic rules, children are particularly ulnerable to pedestrian accidents because many of them have o make regular walking trips to and from school five days a eek and ten months a year. Third, there is reasonable vidence from Edmonton's data that winter-related road onditions are not a significant factor in pedestrian accients; Hillman and Whalley's interpretation is therefore alled into question in the Edmonton situation.

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signal lights: 20 per cent

stop signs: 14 per cent

marked crosswalks: 10 per cent

pedestrian flashers: 5 per cent

pedestrian activated lights: 2 per cent

yield signs: 2 per cent

police/flagmen: 0 per cent

others: 1 per cent

The above figures cannot be compared directly to judge the relative safety effects of different traffic control devices for two reasons. First, the numbers of devices of different types are unknown. This makes it impossible to calculate the ratio between the number of pedestrian accidents and that of devices for each form of traffic control, which should be a better comparative indicator. Second, traffic situations are different at locations with different forms of traffic control. For example, signal lights are mostly installed at busy intersections, but stop signs usually suffice at quieter locations. As Herms (1972) acknowledged, one of the difficulties encountered when conducting a comparative study is the problem of maintaining equivalent conditions.

Nevertheless, two conclusions can be drawn from the above data. First, jaywalking is an important cause of pedestrian accidents, accounting for 46 per cent of the total pedestrian accidents in the residential areas of Edmonton. Since the locations selected for traffic control devices must balance two needs at the same time, efficient flow of vehicular traffic and pedestrian safety, closely-spaced crosswalks are undesirable, especially on heavily trafficked streets whose main function is to channel traffic at relatively high speed. As a result, pedestrians who are reluctant to go out of their way for a traffic-controlled crosswalk are likely to cross streets at uncontrolled locations. Hill (1984) described the decision to cross a street as a "micro-decision", in which pedestrians should, in theory, calculate the risks and benefits of their actions. Because the "legal trajectory" (controlled cross-walks) available to the pedestrian is frequently incongruent with the "free trajectory" (direct, least-effort line), the "free trajectory" is likely to be chosen if it saves time and effort.

Second, while various forms of traffic control at intersections and mid-block crosswalks are necessary pedestrian facilities (they help designate pedestrian right-of-way for specific time periods and at specific locations), their limitations must be recognized so as not to rely on them too much as solutions to pedestrian safety. For instance, at signal light-controlled intersections (mostly busy intersections), pedestrians crossing streets on green lights are still often in conflict with turning vehicles, as described in Section 2.3.1. At pedestrian flasher-controlled crosswalks, impatient drivers are often observed to run through flashing amber lights utilizing small gaps in a pedestrian platoon, because flashers only advise drivers to yield to pedestrians, they do not force them to stop. This may be one explanation why in Edmonton more pedestrian accidents are associated with pedestrian flashers than with pedestrian activated lights. As to marked crosswalks, Fee (1977:450) made the following observation: "Pavement marking alone appears to be too subtle for the motoring public and as a result many vehicles pass through the pedestrian zone [i.e. crosswalk] without stopping or yielding".

5.5 Implications

The above characteristics of pedestrian accidents in Edmonton have four critical implications for the research problem. First, they indicate that the majority of pedestrian accidents in Edmonton happened in its residential areas; the study of residential planning and design for pedestrian safety is therefore pertinent and important. Moreover, pedestrian accidents were unevenly distributed among Edmonton's neighbourhoods; differences in the form of the built environment thus need to be analysed to determine if they can be called on account for the evident differences in pedestrian safety records. Second, school-aged children and elderly people are indeed more vulnerable to pedestrian accidents than other age groups in Edmonton, and should be given particular attention when various environmental configurations are evaluated. In addition, since pedestrian accidents involving school-aged children were likely to be related to their school trips, the spatial organization of schools in relation to their potential service areas and transportation facilities should be considered when pedestrian accident patterns are interpreted at the neighbourhood level. Third, winter-related road conditions are not a particularly significant factor in pedestrian accidents in Edmonton; in other words, they should not diminish the importance of the built environment in accounting for the incidence of pedestrian accidents in Edmonton's residential areas. Finally, regulatory measures do not seem entirely safe on their own for pedestrians. Since they do not physically prevent casual drivers and pedestrians from violating traffic rules, their use cannot be relied on over environmental solutions to ensure the safety of pedestrians, especially young pedestrians who have a weak sense of traffic rules and often show irresponsible walking behaviour (i.e. make pedestrian errors). Through appropriate environmental configuration, however, it should be possible to reduce the opportunities for jaywalking and to minimise the need for costly and disruptive regulatory devices.

In general, these conclusions confirm the validity of the research problem; there is nothing in them that requires any of the research hypotheses to be altered.

CHAPTER 6

MEAN PEDESTRIAN ACCIDENT RATES IN DIFFERENT TYPES OF NEIGHBOURHOODS

Beginning in this chapter, and continuing through the next two, analyses related to the research hypotheses about the role of the built environment in the incidence of pedestrian accidents will be conducted. As the first step in the series, and arising directly from the first research objective, this chapter focuses on the relative safety effects of different types of environmental configuration. In the first two sections of the chapter (6.1 and 6.2), the hypotheses relating to general neighbourhood forms are tested by comparing and ranking mean pedestrian accident rates among Edmonton's five types of neighbourhoods. The findings are then interpreted in Section 6.3 and some implications for the subsequent analyses are drawn out.

The hypotheses to be tested are restated as follows:

1. Unplanned (or grid) neighbourhoods (type 1) have significantly higher mean pedestrian accident rates than planned neighbourhoods in general.

2. As a transitional or partially planned type, modified-grid neighbourhoods (type 2) have mean accident rates lower than grid neighbourhoods but higher than all forms of planned neighbourhoods.

3. Of the planned neighbourhoods of various types, the independently designed units (type 3) have significantly

higher mean pedestrian accident rates than those that are hierarchically organized (types 4 and 5).

4. Among the hierarchically organized neighbourhoods, those of modified Radburn form with separate footpaths (type 4) have lower mean pedestrian accident rates than the cluster-plan neighbourhoods without separate footpaths (type 5).

5. Neighbourhoods consisting of a mix of superblocks and cluster blocks (types 4 and 5) have lower mean intra-neighbourhood pedestrian accident rates than those composed of conventional blocks (types 1, 2 and 3), with the modified Radburns with separate footpaths having the lowest mean rate of all.

As explained in Section 4.2.3, two types of pedestrian accident rates are used in the hypothesized comparisons: gross accident rates and intra-neighbourhood accident rates. The first is used to test hypotheses 1-4; the second for hypothesis 5 only. In each case, the comparisons are conducted first for total neighbourhood population and then for the five age groups defined in Section 4.2.2. The general object is to determine whether the hypothesized benefits of the planned environments apply to all segments of their resident populations, though the safety of school-age children (5-14 years), teenagers (15-19 years) and the elderly (65 and over) is of particular concern since they are the groups known to have the highest accident rates in Edmonton (Figure 5.3). For all comparisons, the general hypothesis is:

$\bar{X}_1>\bar{X}_2>\bar{X}_3>\bar{X}_5>\bar{X}_4$

where $\bar{X}_1$, $\bar{X}_2$, $\bar{X}_3$, $\bar{X}_4$ and $\bar{X}_5$ represent the mean pedestrian accident rates for the five neighbourhood categories, respectively.

6.1 Comparisons of Mean Gross Pedestrian Accident Rates (Hypotheses 1-4)

Table 6.1 shows the mean gross accident rates for the total populations of the neighbourhoods in each of the five types. Arithmetically, the means vary from 11.7 per thousand population for the grid neighbourhoods to 2.1 and 1.8 for the modified-Radburn and cluster-plan neighbourhoods, respectively. Neighbourhoods of the grid type also have the highest standard deviation (7.1), indicating that they vary more in their pedestrian accident rates than do neighbourhoods of any other type.

Table 6.1
Mean gross pedestrian accident rates for total neighbourhood populations in the five types of neighbourhoods, Edmonton, 1982-1990

Neighbourhood type	Numbers of neighbourhoods	Mean pedestrian accident rate	Standard deviation
1	42	11.7	7.1
2	19	5.9	3.4
3	37	3.8	3.9
4	33	2.1	1.3
5	22	1.8	2.0

To test if the differences in mean gross accident rates are statistically significant, an ANOVA was performed. Table 6.2 shows the statistical hypotheses and F-test result. Since the computed F-ratio (33.08) is much greater than the critical F-ratio (2.37), H_0 is rejected and H_1 is accepted, meaning that at least two of the means are significantly different. To find out which means these are, the analysis then proceeded to the Two-Sample Difference-of-Means Test.

Table 6.2
Statistical hypotheses and F-test result using gross pedestrian accident rates for total neighbourhood populations in the five types of neighbourhoods

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
$H_0: \bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	33.08	2.37	reject H_0

Table 6.3 presents the series of statistical hypotheses and the corresponding t-test results. It demonstrates that type 1 (i.e. grid or unplanned) neighbourhoods indeed outrank all others in terms of mean gross accident rate for total neighbourhood populations; type 2 (or modified-grid) neighbourhoods have the second highest mean accident rate; type 3 (the independent) neighbourhoods have a mean higher than those of types 4 and 5, the hierarchically organized neighbourhoods; but no difference can be determined between the last two.

Table 6.3
Statistical hypotheses and t-test results using gross pedestrian accident rates for total neighbourhood populations in the five types of neighbourhoods

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.000	59	3.34	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	56	6.39	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	44	7.67	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	52	6.43	1.67	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.007	32	2.57	1.70	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	21	5.83	1.72	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.000	28	4.88	1.70	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.002	50	2.92	1.68	reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.004	56	2.79	1.67	reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.792	32	-0.82	1.70	do not reject H_0

Hypotheses 1, 2 and 3 were therefore confirmed, but hypothesis 4 was rejected. That is, on average, cluster-plan neighbourhoods are just as safe for pedestrians as modified-Radburn neighbourhoods, and both are significantly safer than independent neighbourhood units which, in turn, are safer than modified-grid neighbourhoods; in general, all four types are significantly safer than grid neighbourhoods.

The procedure was then repeated for the separate age groups. However, to avoid the tediousness of describing every round of ANOVA and the Two-Sample Difference-of-Means Test, the mean accident rates are summarized in Table 6.4; the tables showing the F-test and t-test results can be found in Appendices 1-10. The rest of this section focuses on ranking the five types of neighbourhoods for each age group.

Table 6.4
Mean gross pedestrian accident rates for different age groups in the five types of neighbourhoods

Neighbourhood type	Mean pedestrian accident rate				
	0-4 years	5-14 years	15-19 years	20-64 years	65 years and over
1	5.7	35.2	20.1	8.6	10.7
2	2.2	17.0	14.6	3.7	4.8
3	2.7	10.7	8.9	2.0	2.0
4	1.8	5.7	3.2	0.8	1.7
5	1.2	4.2	4.9	0.8	0.6

The analysis of variance indicates that the mean accident rates vary statistically among the five types of neighbourhoods for every age group. Their actual rankings, as determined by the Two-Sample Difference-of-Means Test, are described below.

1. For pre-schoolers (0-4 years), type 1 neighbourhoods have the highest mean pedestrian accident rate, but no significant differences can be determined among the other four

categories.

2. For children 5-14 years old, the established rank is as follows (from high to low): type 1; type 2; type 3; types 4 and 5. This is exactly the same as the ranking for total neighbourhood populations.

3. For children of 15-19 years, the ranking is more complicated. This time, no significant difference can be determined between type 1 and 2 neighbourhoods, though both have higher mean pedestrian accident rates than any other category. Type 3 neighbourhoods have a mean that is statistically higher than the mean for type 4, but not higher than type 5. On the other hand, no difference can be determined between type 4 and 5 neighbourhoods. From this ranking, only a broad conclusion can be drawn: that is, planned neighbourhoods in general are safer than unplanned and partially planned ones for the 15-19 years age group.

4. With regard to mean adult-pedestrian accident rates, the ranking is as follows: type 1; type 2; type 3; types 4 and 5. Once again, this is the same ranking as for total neighbourhood population.

5. With respect to elderly people, type 1 neighbourhoods again have the highest mean pedestrian accident rates and type 2 neighbourhoods have the second highest mean, but there is no significant difference among types 3, 4 and 5, the various forms of planned neighbourhoods.

To sum up, hypothesis 1 is proved for all age groups.

Hypothesis 2 is confirmed for children of 5-14 years, adults of 20-64 years and the elderly, but not for children of 0-4 and 15-19 years. Hypothesis 3 is accepted for children of 5-14 years and adults, but rejected for other age groups. Hypothesis 4 is rejected for all age groups.

6.2 Comparisons of Mean Intra-neighbourhood Pedestrian Accident Rates (Hypothesis 5)

Table 6.5 shows the mean intra-neighbourhood pedestrian accident rates for total neighbourhood populations in the five types of neighbourhoods. They range from 4.8 for unplanned neighbourhoods to 1.1 and 0.8 for fully planned neighbourhoods. The analysis of variance (see Table 6.6) indicates that at least two means in Table 6.5 are statistically different, and the Two-Sample Difference-of-Means Test (see Table 6.7) produced the following ranking: type 1; type 2; types 3, 4 and 5. In other words, type 1 neighbourhoods composed of regular (or grid) conventional blocks again have the highest mean

Table 6.5
Mean intra-neighbourhood pedestrian accident rates for total neighbourhood populations in the five types of neighbourhoods

Neighbourhood type	Number of neighbourhoods	Mean pedestrian accident rate	Standard deviation
1	42	4.8	5.3
2	19	1.8	1.1
3	37	1.1	1.1
4	33	1.1	0.8
5	22	0.8	1.2

Table 6.6
Statistical hypotheses and F-test result using intra-neighbourhood pedestrian accident rates for total neighbourhood populations in the five types of neighbourhoods

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	13.08	2.37	reject H_0

Table 6.7
Statistical hypotheses and t-test results using intra-neighbourhood pedestrian accident rates for total neighbourhood populations in the five types of neighbourhoods

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq 0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.000	48	2.54	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq 0$ H_1: $\bar{X}_1-\bar{X}_3>0$	[illegible].000	45	4.30	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq 0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	43	4.13	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq 0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	44	3.55	1.67	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq 0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.014	40	2.25	1.70	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq 0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.004	30	2.79	1.72	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq 0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.001	31	3.35	1.70	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq 0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.484	64	0.04	1.68	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq 0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.215	57	0.79	1.67	do not reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq 0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.834	49	-0.98	1.67	do not reject H_0

accident rate, and type 2 neighbourhoods with a mix of regular and irregular conventional blocks have the second highest, but no difference can be determined among the three types of fully planned neighbourhoods. Hypothesis 5 is therefore only partially accepted. This means that the interior streets of neighbourhoods with superblocks and cluster blocks (types 4 and 5) are safer on average than those with regular conventional blocks, as hypothesized, but they are not safer than those neighbourhoods that are characterized by irregular conventional blocks (type 3). The hypothesized difference between neighbourhoods of types 4 and 5 is also disproved; on average, the interior streets of modified Radburn neighbourhoods are not safer for pedestrians than those of cluster-plan neighbourhoods.

The comparison of mean intra-neighbourhood pedestrian accident rates was then repeated for the five age groups. As in Section 6.1, only the actual means are shown here (see Table 6.8). The tables presenting the F-test and t-test results are in Appendices 11-19.

The analysis of variance indicates that there is no statistical variation among the mean intra-neighbourhood pedestrian accident rates for pre-schoolers (0-4 years), so hypothesis 5 must be rejected in this instance. For all other age groups, however, it can be partially accepted on almost the same terms as for total population. That is, type 1 neighbourhoods always rank first, and so in general are least

Table 6.8
Mean intra-neighbourhood pedestrian accident rates for different age groups in the five types of neighbourhoods

Neighbourhood type	Mean pedestrian accident rate				
	0-4	5-14	15-19	20-64	65 and over
1	3.9	18.2	7.4	3.1	4.5
2	1.1	6.3	3.0	0.9	1.1
3	2.8	6.1	1.8	0.5	0.3
4	2.0	3.7	1.0	0.4	0.0
5	1.6	2.9	2.1	0.5	0.4

safe in their interiors, but there are no statistical differences among neighbourhoods of types 3, 4 and 5. The rank of type 2 neighbourhoods is more variable, but they are never safer on average than the fully planned neighbourhoods for any age group. In all cases, then, the significant differences are between planned and unplanned configurations, and not among the three block types (irregular conventional block, cluster block and superblock) that planners have adopted in preference to regular grid blocks.

6.3 Conclusions

There are clear variations in mean pedestrian accident rates among the different types of neighbourhoods in Edmonton, though not exactly as hypothesized. In general, however, planned neighbourhoods of all types are safer than unplanned ones, whether all accidents are considered or just those that occurred in neighbourhood interiors (i.e. excluding accidents on boundary streets). By and large, this generalization also holds good for each of the five age groups into which the neighbourhood populations were divided; there are exceptions but they are of minor importance.

The following more specific conclusions are germane to the research problem:

1. By almost every measure that was used in the analysis, grid neighbourhoods constitute the most hazardous type of residential environment in Edmonton. The only exception was the mean intra-neighbourhood pedestrian accident rate for children of 0-4 years, and even then, grid neighbourhoods were no safer on average than any other type of neighbourhood.

2. For the most part, as befits their transitional status, modified-grid neighbourhoods are safer on average than grid neighbourhoods but not as safe as planned ones of any type. This does not always hold true for specific age groups but it is the case for total population whichever accident rate measure is employed. This conclusion is important because it indicates that even moderate changes to environmental configuration can bring real benefits in pedestrian safety. The modifications that were made to street and block patterns and to land use arrangements under Edmonton's replotting procedure were sufficient to produce significant improvements in mean pedestrian accident rates.

3. The independent or conventional neighbourhood units that were the norm in Edmonton from about 1955 to the late

1960s have a significantly higher mean gross pedestrian accident rate than either of the types of hierarchically-organized neighbourhoods that were built subsequently. In terms of mean intra-neighbourhood accident rates, however, no significant differences were found, either for total population or for any age group. On average, the interior streets of all three types of neighbourhoods are equally safe, which implies that the higher gross accident rates in independent neighbourhood units are caused by accidents on their boundary streets. This has already been anticipated in hypothesis 7 and will be examined more closely in the next chapter.

4. No significant differences, by any measure, were found between modified-Radburn and cluster-plan neighbourhoods. This was an unexpected result and it has a most important implication for the thesis. Given that the characteristic street, block and land use patterns of these two types of neighbourhoods are essentially the same, the significant point of difference between them, in terms of environmental configuration, is that the modified-Radburn neighbourhoods have separate footpath networks. The findings reported here therefore suggest that the separation of pedestrians has no particular safety advantage over the more traditional accommodation approach, all other things being equal. This possibility will be examined more directly in Chapter 7, when hypothesis 10 is tested.

5. With respect to the separate age groups, the main

implications of the analytical results are as follows:

(a) Very young children (0-4 years) have low mean pedestrian accident rates in neighbourhoods of all types, and for the most part there are no significant differences among them. This no doubt reflects the fact that when young children are walking in residential areas they are usually under close supervision. Environmental modifications therefore have little relevance to them.

(b) Almost without exception, school-age children (5-14 years) have the highest mean pedestrian accident rates for every neighbourhood type. The evidence also indicates that they are particular beneficiaries of the changes in environmental configuration that the different types of neighbourhoods represent. Most importantly, neighbourhoods that belong to hierarchically-organized units are the safest of all, on average, for this group, though the difference shows up more strongly for gross pedestrian accident rate than it does for the intra-neighbourhood rate. This is significant because this group comprises children of elementary and junior high school age, many of whom must walk regularly between neighbourhoods on their journeys to and from school. The analyses in this chapter suggest that inter-neighbourhood trips are safer for school-age children in a hierarchical structure than in independent neighbourhood units.

(c) The same general conclusion can be applied to the teenage population group (15-19 year), though the supporting evidence is not as strong. Still, it is evident that teenagers benefit from planned environments in general, which is important in itself. Although they are likely to walk less frequently than younger children, and experience lower mean pedestrian accident rates, these rates are relatively high by Edmonton standards. The indication that they can be reduced through environmental configuration is therefore significant.

(d) In contrast to the two previous age groups, the large adult population (20-64 years) has relatively low mean pedestrian accident rates in neighbourhoods of all types. Nonetheless, planned environments in general are significantly safer for this group than unplanned ones. Once again, too, the difference in accident risk among the types of planned neighbourhoods appears to be chiefly associated with the boundary streets of independent neighbourhood units.

(e) Finally, for the elderly (65 years and over), planned neighbourhoods are, in general, safer than unplanned ones, but there are no significant differences in mean pedestrian accident rates among the various types of planned neighbourhoods. In particular, the elderly do not appear to benefit from the special features of modified-Radburn and cluster-plan neighbourhoods in hierarchical structures. This may reflect the fact that they do not make frequent inter-neighbourhood pedestrian trips, unlike school-age children and teenagers, who are the main beneficiaries of these particular environmental configurations.

6. Accident rates vary within every neighbourhood type, but grid neighbourhoods vary more among themselves than do neighbourhoods of other types, as indicated by their relatively large standard deviations (Tables 6.1 and 6.5). It is also noteworthy that modified-grid neighbourhoods and independent neighbourhood units have larger standard deviations than hierarchically-organized neighbourhoods for gross accident rates but not for intra-neighbourhood rates. This points, yet again, to the important role of boundary streets and the possibility that different forms of boundaries have different effects in the older types of planned neighbourhoods. This has been anticipated in hypothesis 13 and will be examined in Chapter 8, along with the effects of other local variations in environmental configuration.

CHAPTER 7

PEDESTRIAN ACCIDENTS IN RELATION TO STREET PATTERNS AND FOOTPATH NETWORKS

In Chapter 6, where the first research objective was addressed, it was proved that planned neighbourhoods in Edmonton are safer in general for pedestrians than unplanned grid neighbourhoods, and that neighbourhoods of the modified-Radburn and cluster-plan types are, on average, the safest of all. From this broad conclusion it is logical to proceed to more detailed analyses, to attempt to determine whether the relative safety of these different types of neighbourhoods, including the lack of a measurable difference between the two hierarchically organized types, can be attributed to specific variations in the forms of the environmental design elements with which they are characteristically configured. That is, to assess the safety effects of the different forms as they have been employed in Edmonton, and hence gain a better appreciation of their respective influences on the overall safety of the general neighbourhood forms.

As the first step in meeting this second research objective, the analyses in Chapter 7 focus on the different forms of circulation systems, both vehicular and pedestrian. As explained in Section 4.1.2, there are two reasons for this approach. First, all the accidents that are being analyzed occurred on streets, so it is important to investigate their relationships with those features of the street environment that were identified in Chapter 2 as bearing most directly on pedestrian safety. Second, Edmonton's 5 types of neighbourhoods are primarily differentiated from one another by their particular forms and combinations of street patterns and pedestrian facilities. Of all the design elements these two should have the most immediate influence on the neighbourhood rankings that were established in Chapter 6. With this in mind, Chapter 7 was designed to test the following hypotheses:

6. Pedestrian accident rates are positively correlated with each of street density, intersection density and the number of neighbourhood entrances/exits in the study neighbourhoods; for this reason, the rank of mean pedestrian accident rates matches the ranks of these three street-related factors among different types of neighbourhoods.

7. (a) Most pedestrian accidents happen on neighbourhood boundary streets; (b) in relation to neighbourhood forms, the boundary streets of unplanned grid neighbourhoods court more pedestrian accidents than those of planned neighbourhoods, and the proportion of accidents on boundary streets is significantly higher in the areas laid out as independent neighbourhood units than in areas of hierarchical organization.

8. Of the various forms of residential access streets, culs-de-sac are the safest, and short loops are safer than straight (grid) streets.

9. Among the various forms of intersections, T-intersections are generally the safest in residential areas.

10. Pedestrian accident rates are negatively correlated with footpath density, especially for school-age children who are more likely than other age groups to use footpaths to walk to schools and playgrounds.

7.1 Correlation Analyses between Pedestrian Accident Rates and Street Density, Intersection Density, and the Number of Neighbourhood Entrances/Exits (Hypothesis 6)

Since the results of the correlation analyses will be used to explain the variations in mean pedestrian accident rates among the different types of neighbourhoods, it is pertinent to demonstrate at the outset that the density of streets, the density of intersections and the number of entrances/exits also differ by neighbourhood type. Table 7.1 tabulates the means of each of these variables for the five types of neighbourhoods in Edmonton. Street density is expressed as the average length of streets (in metres) per 100

Table 7.1
Means of street density, intersection density and the number of entrances/exits for the five types of neighbourhoods

Neighbourhood type	Number of neighbourhoods	Mean street density	Mean intersection density	Mean number of entry points
1	42	14,500	0.57	18.3
2	19	12,600	0.43	12.2
3	37	11,900	0.37	7.0
4	33	10,100	0.32	4.5
5	22	9,800	0.30	4.2
Total	153	11,800	0.40	9.2

hectares; intersection density is expressed as the average number of intersections per 100 hectares; and the number of entrances/exits refers to all the points of access from the boundary streets of a neighbourhood.

Arithmetically, the category means in Table 7.1 vary among the different types of neighbourhoods and always in the same order. The following hypothesis can therefore be formulated for all three factors:

$$\bar{X}_1>\bar{X}_2>\bar{X}_3>\bar{X}_4>\bar{X}_5$$

where $\bar{X}_1$, $\bar{X}_2$, $\bar{X}_3$, $\bar{X}_4$ and $\bar{X}_5$ represent the mean street density, or mean intersection density, or the mean number of neighbourhood entrances/exits for the five neighbourhood types, respectively. As in Chapter 6, this hypothesis was tested using the techniques of ANOVA and the Two-Sample Difference-of-Means Test. (See Appendices 20-25 for the test results.)

In terms of mean street density, the five types of neighbourhood are statistically ranked as follows (in descending order): type 1; types 2 and 3; types 4 and 5. As to mean intersection density and the mean number of entrances/exits, the rank is slightly different: type 1; type 2; type 3; types 4 and 5. In summary, type 1 neighbourhoods (grid subdivisions) have the highest street density on average, as well as the highest intersection density and the greatest number of entry/exit points. Type 2 neighbourhoods are similar to type 3 neighbourhoods in terms of mean street density, but have a higher mean intersection density and more entry points. Type

4 and 5 neighbourhoods rank lowest on all three variables, but in no case is there a significant difference between them.

The analysis now shifts to the general (or bivariate) correlation analysis between the incidence of pedestrian accidents and the three street-related factors featured in Table 7.1. All 153 neighbourhoods that were developed before 1982 are included in this analysis.

Table 7.2 summarizes the correlation coefficients. As can be seen, pedestrian accident rates indeed have positive correlations with neighbourhood street density (r=0.40), with intersection density (r=0.51) and with the number of entrances/exits (r=0.63); in terms of relative importance, the number of entrances/exits contributes most to pedestrian accident rates, followed by intersection density and street density. Hypothesis 6 is therefore confirmed in this respect.

Table 7.2
Matrix of correlation coefficients

	Accident rate	Street density	Intersection density	Entry points
Accident rate	1.00	0.40	0.51	0.63
Street density		1.00	0.86	0.65
Intersection density			1.00	0.73
Entry points				1.00

Since Table 7.2 also demonstrates that the three street-related variables are highly correlated with each other, however, it needs to be verified if their relative importance still holds true when the confounding effects between them are controlled. This is done through partial correlation analysis, the results from which are presented in Table 7.3. The diagonal elements are all displayed as -1.00 to emphasize that they are irrelevant. The other partial correlation coefficients all appear weaker than the corresponding coefficients in Table 7.2, but the rank or relative importance of the three street-related factors remain the same when correlated with pedestrian accident rates. The only unexpected result is that the correlation coefficient for street density is reduced from +0.40 to -0.16, but that does not necessarily mean that street density is irrelevant to the incidence of pedestrian accidents. Because street density and intersection density are

Table 7.3
Matrix of partial correlation coefficients

	Accident rate	Street density	Intersection density	Entry points
Accident rate	-1.00	-0.16	0.28	0.46
Street density		-1.00	0.74	0.14
Intersection density			-1.00	0.30
Entry points				-1.00

always in consonance with each other in any street network, the negative coefficient should be interpreted to mean that high street density contributes to pedestrian accidents mainly by creating more intersections.

The general implication, based on the positive correlations uncovered in Table 7.2, is that the more entrances/exits a neighbourhood has, and the higher its density of intersections and streets, the more likely it is that pedestrian accidents will occur there. This conclusion can then be used as the ground to link the rank of mean pedestrian accident rates for the five types of neighbourhoods (as revealed in Chapter 6) to the ranks of the three street-related variables (as determined earlier in this section). Table 7.4 shows that the rank of mean gross pedestrian accident rates matches exactly those of intersection density and the number of entrances/exits for the five types of neighbourhoods, and

Table 7.4
Ranks of mean pedestrian accident rates, mean street density, mean intersection density and the mean number of entrances/exits for the five types of neighbourhoods in Edmonton

Neighbourhood type	Ranks				
	gross accident rate	intra-neighbourhood accident rate	street density	intersection density	number of entrances/exits
1	1	1	1	1	1
2	2	2	2	2	2
3	3	3	2	3	3
4	4	3	3	4	4
5	4	3	3	4	4

nearly matches that of street density, the variable that has the weakest correlation with pedestrian accident rate. The ranks of mean intra-neighbourhood accident rates and the three street-related variables match well for unplanned (type 1), partially planned (type 2) and fully planned (types 3, 4 and 5) neighbourhoods, but not for fully planned neighbourhoods of different types. The grid (or unplanned) neighbourhoods ranked first on all three street-related factors; they also have the highest mean pedestrian accident rates (both gross and intra-neighbourhood). Correspondingly, the modified-grid neighbourhoods ranked second on the same three factors, and have the second highest mean pedestrian accident rates. Among the various forms of fully planned neighbourhoods, types 4 and 5 (hierarchically organized Radburn-type and cluster-plan neighbourhoods) have fewer entry points, lower intersection density and lower street density than type 3 (independent neighbourhood units); they also have lower mean gross pedestrian accident rates, though their mean intra-neighbourhood accident rates are not significantly lower. On the other hand, there are no statistical differences between types 4 and 5 in terms of any of the three street-related factors, just as the analyses in Chapter 6 found no differences between them with regard to either type of pedestrian accident rate. In this respect, too, Hypothesis 6 is confirmed.

These findings lead to a significant conclusion: fully planned neighbourhoods of all forms, but especially the modified-Radburn and cluster-plan neighbourhoods, provide safer pedestrian environments because their street density, their intersection density and especially their numbers of entry points are significantly reduced through conscious design. These street-related factors may not be the only ones that contribute to this result, but they certainly play an important role in reducing overall pedestrian accident rates in planned residential environments.

7.2 Relations between Pedestrian Accidents and Types of Streets (Hypotheses 7 and 8)

To reiterate, 3032 pedestrian accidents occurred in Edmonton's residential areas during the study period. Table 7.5 cross-tabulates these accidents by street type, both in total and for each of the five types of neighbourhoods. Three observations can be made in relation to Hypotheses 7 and 8.

Table 7.5
Frequency of Pedestrian accidents in relation to different types of streets in the five neighbourhood types, Edmonton, 1982-1990
(numbers in parentheses are percentages)

	Neighbourhood type					
	1	2	3	4	5	Total
Boundary street	1026 (53)	253 (68)	242 (69)	120 (49)	51 (41)	1692 (56)
Collector street	658 (34)	75 (20)	70 (20)	108 (44)	54 (43)	965 (32)
Straight access street	193 (10)	22 (6)	11 (3)	0 (0)	1 (1)	227 (8)
Short loop street	2 (<1)	11 (3)	18 (5)	14 (6)	12 (10)	57 (2)
Cul-de-sac	0 (0)	4 (1)	0 (0)	2 (<1)	4 (3)	10 (<1)
Service road/backlane	58 (3)	8 (2)	11 (3)	1 (<1)	2 (2)	80 (2)
Total	1937 (100)	373 (100)	352 (100)	245 (100)	124 (100)	3032 (100)

First, 56 per cent of all the pedestrian accidents in residential areas happened on neighbourhood boundary streets. Sixty-one per cent of this set of accidents were in type 1 neighbourhoods alone, and the accident density on grid boundary streets was as high as 7.6 accidents per kilometre (see Table 7.6). Another 15 per cent of the boundary street accidents occurred in type 2 neighbourhoods (with an average of 3.5 accidents per kilometre); 14 per cent took place in type 3 neighbourhoods (2.6 accidents per kilometre); and only 6 per cent and 3 per cent occurred in type 4 and 5 neighbourhoods (with 1.4 and 1.0 accidents per kilometre, respectively). This result demonstrates that the boundary streets of unplanned neighbourhoods are indeed more hazardous for pedestrians than those of planned neighbourhoods. It is also noteworthy that the rank of accident density on boundary streets for the five neighbourhood types matches the rank of

Table 7.6
Pedestrian accident density on boundary streets of the five types of neighbourhoods, Edmonton, 1982-1990

Neighbourhood type	Accident density (accidents/km)
1	7.6
2	3.5
3	2.6
4	1.4
5	1.0
Total	3.6

neighbourhood entrances/exits (Table 7.1), the street-related factor that has proved to have the strongest correlation with the incidence of pedestrian accidents. On boundary streets, where traffic is usually heavy and travel speeds high, more neighbourhood entrances mean more intersections, more crosswalks, and therefore more points of conflict between pedestrians and vehicles.

Second, the proportion of pedestrian accidents on boundary streets is higher in independently designed neighbourhoods (type 3) than in those that are hierarchically organized (types 4 and 5): about 70 per cent in the former and less than 50 per cent in the latter. This conforms to the expectation that in the independent neighbourhood units, which are rarely self-contained and are mostly bounded by arterial streets, inter-neighbourhood pedestrian trips are unduly subject to accident hazards. This problem is exacerbated by the fact that independent neighbourhood units tend to have more entrances/exits as well. It is also revealing to see that modified-grid neighbourhoods resemble independent neighbourhood units rather than grid neighbourhoods in the proportion of pedestrian accidents on boundary streets. This indicates that while the modified-grid neighbourhoods were made generally safer by changing their original grid street layouts and applying neighbourhood unit principles, they suffer from the same problems of land use organization and boundary treatment as full neighbourhood units.

Third, as to the various forms of access streets, including service roads and backlanes, there were more pedestrian accidents on straight access streets (8 per cent of the total accidents in residential areas) than on any others (see the "Total" column in Table 7.5). Short-loop streets had fewer accidents (2 per cent of the total), and culs-de-sac the fewest (less than 1 per cent of the total accidents in residential areas). It is also notable that while type 4 and type 5 neighbourhoods are characterized by similar street patterns, the proportion of pedestrian accidents on access streets is lower in the former (7 per cent) than in the latter (16 per cent). This suggests that the footpath networks in type 4 neighbourhoods might help to divert pedestrian trips from access streets, so reducing pedestrian-vehicle conflicts, a possibility that is addressed in Section 7.4.

Taken together, these observations confirm Hypotheses 7 and 8 without qualification.

7.3 Relations between Pedestrian Accidents and Intersections (Hypothesis 9)

In the residential areas of Edmonton, four distinctive forms of intersections can be identified. Their distribution by neighbourhood category is shown in Table 7.7. The cross-intersection is the dominant form in unplanned residential areas (type 1 neighbourhoods), whereas T-intersections are the most common form in planned neighbourhoods (types 3, 4 and 5), and even in modified-grid neighbourhoods. Acute-intersections

Table 7.7
Distribution of different forms of intersections in the five types of neighbourhoods (in percentages)

	Neighbourhood type					
	1	2	3	4	5	Total
Cross-intersection	65	34	21	23	22	40
T-intersection	27	56	73	77	78	54
Acute-intersection	8	10	6	0	1	6
Traffic circle	<1	0	<1	0	0	<1
Total	100	100	100	100	100	100

are mostly found in inner-city areas where regular grid streets were interrupted by former irregular trails (such as University Avenue, Fort Road, St Albert Trail and Stony Plain Road) or where the street layout was dictated by local terrain features, such as rivers and ravines. Traffic circles are a rare form of intersection; only 8 were counted in Edmonton's residential areas, all of them on busy boundary streets.

In the study period (1982-1990), 1676 pedestrian accidents were recorded as having happened at intersections in residential areas, accounting for 55 per cent of all the residential accidents. They are tabulated in Table 7.8 in relation to the various forms of intersections as well as to the five types of neighbourhoods. This reveals that 69 per cent of the total set of accidents were at cross-intersections, which account for only 40 per cent of all intersections in residential areas (see the "Total" column in Table 7.7). By contrast, 23 per cent of the pedestrian accidents took place

Table 7.8
Pedestrian accidents in relation to different forms of intersections in the five types of neighbourhoods (in percentages)

	Neighbourhood type					Total
	1	2	3	4	5	
Cross-intersection	77	46	55	47	49	69
T-intersection	14	42	38	53	49	23
Acute-intersection	7	11	1	0	2	6
Traffic circle	2	1	6	0	0	2
Total	100	100	100	100	100	100

at T-intersections, which account for 54 per cent of all intersections. Smaller proportions, 6 per cent and 2 per cent, occurred at acute-intersections and traffic circles, which account for 6 and 0.1 per cent of the total intersections respectively.

For a clearer picture, relations between pedestrian accidents and the various forms of intersections are expressed with another variable, viz. the ratio between the number of intersections of a particular kind and the number of pedestrian accidents associated with that particular type of intersection. Because of the small number of traffic circles, they were excluded from the comparison. The results in Table 7.9 show that cross-intersections and acute-intersections indeed have more pedestrian accidents per intersection (4.3 and 2.6 times higher) than do T-intersections. Obviously, then, Hypothesis 9 is accepted, meaning that T-intersections are generally the safest for pedestrians, as planners assume.

Table 7.9
Ratio between numbers of intersections of different forms and numbers of pedestrian accidents, Edmonton, 1982-1990

Form of intersection	Ratio between numbers of intersections of different forms and numbers of accident
Cross-intersection	1:0.43
T-intersection	1:0.10
Acute-intersection	1:0.26

Further evidence about the relative safety effects of cross- and T-intersections, the two most common forms of intersections in residential areas, is provided in Figure 7.1. The point to note is that the percentage of pedestrian accidents at cross-intersections is consistently higher than the proportion of cross-intersections in all five types of neighbourhoods, whereas the percentage of accidents at T-intersections is consistently lower. This indicates that cross-intersections indeed court more pedestrian accidents than T-intersections, regardless of neighbourhood configuration. The more cross-intersections there are in any neighbourhood, of whatever type, the greater the likelihood of pedestrian accidents.

7.4 Associations between Pedestrian Accidents and Footpath Networks in Type 4 Neighbourhoods (Hypothesis 10)

In theory, there should be a negative correlation between pedestrian accident rate and footpath density. Because footpaths separate pedestrians from streets, the more footpaths that are provided, the fewer pedestrians who should walk

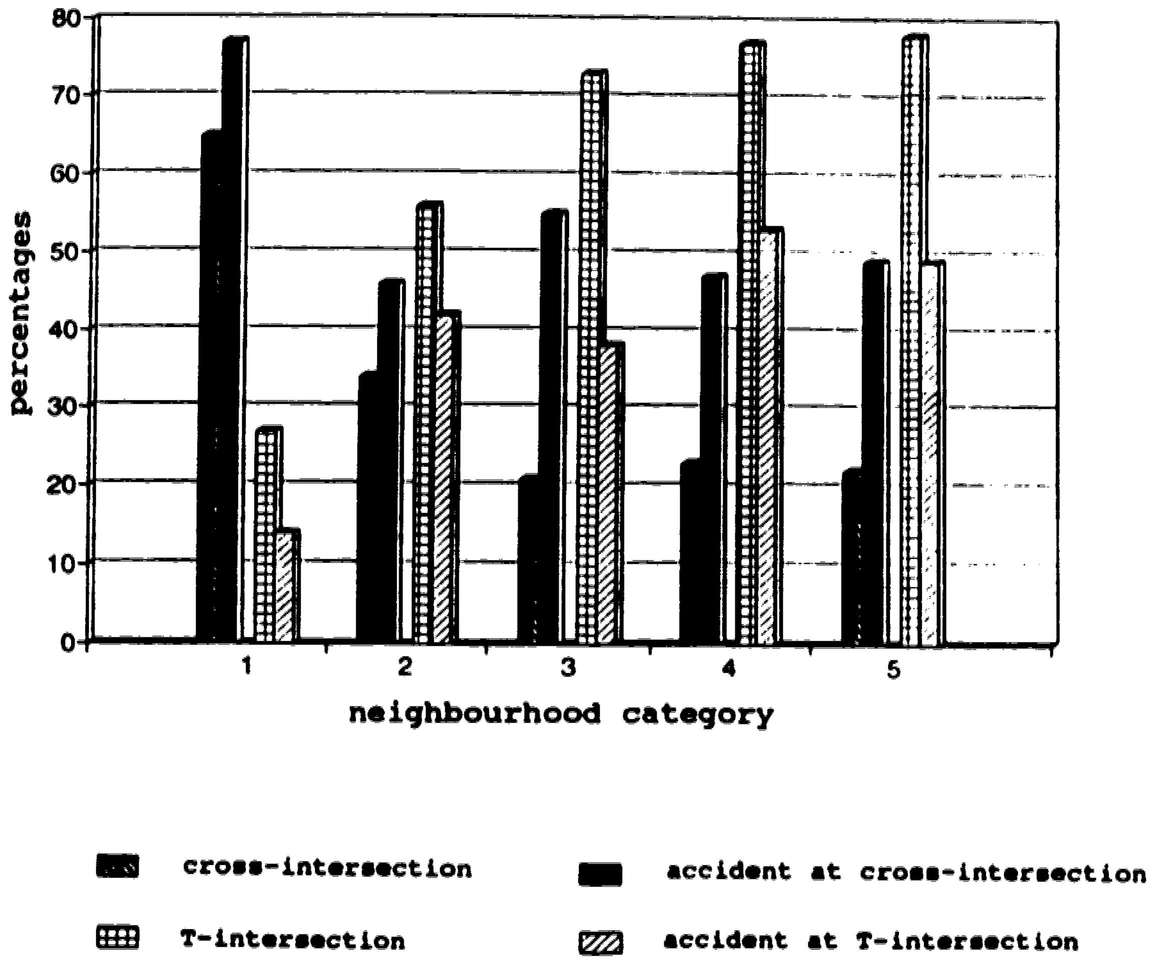

Figure 7.1 Percentages of pedestrian accidents at T- and cross-intersections versus percentages of T- and cross-intersections, in the five types of neighbourhoods in Edmonton, 1982-1990

along or across streets, thus reducing the potential for conflict between pedestrians and vehicles. To this point in the thesis, however, contradictory interpretations have emerged. First, in chapter 6, it was found that there was no significant difference in mean pedestrian accident rates between modified-Radburn neighbourhoods and cluster-plan neighbourhoods. Since their only environmental difference is that the former have separate footpath networks whereas the latter do not, doubt is cast upon the safety advantages of separate footpaths. Against this, in Section 7.2, it was suggested that separate footpaths, because they divert pedestrians from the street network, might explain why the proportions of accidents on access streets are lower in modified-Radburn neighbourhoods than in cluster-plan neighbourhoods. Testing Hypothesis 10 should clarify this issue.

As the first part of the investigation into the safety effects of separate footpaths, a correlation analysis between footpath density (metres of footpaths per hectare) and pedestrian accident rates in modified-Radburn neighbourhoods was performed. The investigation was limited in this way for the obvious reason that separate footpaths are not characteristic of any other neighbourhood type. The analysis was conducted for total population and for the regular five age groups. The expectation here was that separate footpaths should at least help to reduce the accident rates of school-age children, if not the population as a whole, because footpaths in Edmonton most often link dwelling clusters to parks, playgrounds and schools, and children are more likely than other age groups to use them to walk to their most frequented destinations.

Before examining the correlations, it is necessary to establish that footpath density does vary among the 33 neighbourhoods of type 4. In fact, it varies substantially, as Table 7.10 demonstrates. The range in density is from 8 to 58 metres per hectare and the standard deviation is 11 metres per hectare. If, as hypothesized, the pedestrian accident rates of these 33 neighbourhoods are negatively correlated with footpath density, the data in Table 7.10 raise the further possibility that the expected difference in mean pedestrian accident rates between type 4 and type 5 neighbourhoods may have been blurred by those type 4 neighbourhoods that have a low footpath density, and so most nearly resemble those in type 5.

Table 7.11 summarizes the results of the correlation analysis for all five age groups and for total neighbourhood populations. The only negative correlation occurs for the age

Table 7.10
Summary statistics for Footpath Density

Number of neighbourhoods	33
Average footpath density	23 (m/ha)
Standard deviation	11 (m/ha)
Minimum	8 (m/ha)
Maximum	58 (m/ha)

Table 7.11
Summary results of the correlation analysis between footpath density and pedestrian accident rates for different age groups

Age group	Number of neighbourhoods	Correlation coefficients	Probability
0-4	33	-0.07	0.704
5-14	33	0.25	0.160
15-19	33	0.39	0.030
20-64	33	0.36	0.040
65+	33	0.05	0.760
Total population	33	0.47	0.010

group 0-4 years, but it is extremely weak (r=-0.07) and has no significance. The correlations for other age groups are all positive and so contradict the research hypothesis. As a result, Hypothesis 10 is rejected completely. This indicates that neighbourhoods with relatively high footpath densities, and hence more complete footpath networks, are not necessarily safer for any age group than those with fewer footpaths and a lower footpath density. This result clearly reinforces the finding from Hypothesis 4 that modified-Radburn neighbourhoods are not safer on average than cluster-plan neighbourhoods for any age group. Conversely, it offers no support for the suggestion that the previous finding might be attributed to the low footpath density of some of the modified-Radburn neighbourhoods. Nor does it help to explain the apparently greater safety of access streets in type 4 neighbourhoods in general; that is more likely to have been a spurious inference given the low frequency of pedestrian accidents on access streets in planned neighbourhoods of all types (see Table 7.5)

One possible explanation for the unexpected result given by the correlation analysis is that because footpaths in Edmonton cross streets at grade, in contrast to the grade-separated crossings of the original Radburn concept, they create more "intersections", or conflict points, on boundary and collector streets. The locations of all 235 pedestrian accidents in type 4 neighbourhoods were therefore examined on air photos. In fact, only 27 of them (11 per cent) were found to have occurred near the junctions of footpaths and streets; among the rest, 85 (36 per cent) were at street intersections, and 127 (53 per cent) were at other mid-block locations (other than in the vicinity of the junctions of footpaths and streets). It can therefore be concluded that grade crossings do not account for the fact that mean pedestrian accident rates in modified-Radburn neighbourhoods are not significantly lower than those in cluster-plan neighbourhoods. The more likely explanation, considering where on the street most accidents in type 4 neighbourhoods occur, is to be found in the typical design of Edmonton's footpath networks. Unlike the true Radburn form, where all blocks are superblocks and it is deliberately made difficult for pedestrians to have access to streets, people walking in Edmonton's modified-Radburn neighbourhoods can more readily choose routes that follow and cross streets in the conventional way.

7.5 Conclusions

In this chapter, relations between the incidence of pedestrian accidents and various aspects of street patterns and footpath networks were investigated. Since these two features, which together form the circulation systems used by both vehicles and pedestrians, are the most explicit differentiating factors of environmental configuration, the findings reported here go a long way towards explaining the variations in overall pedestrian safety among the five types of neighbourhoods in Edmonton.

Most generally, as the chapter clearly reveals, street pattern is an environmental design element that has major implications for pedestrian safety. First of all, pedestrian accident rates are positively correlated with street density, intersection density and especially the number of neighbourhood entrances/exits. For this reason, it can be concluded that the fact that unplanned grid neighbourhoods recorded the highest rankings for all three factors is largely responsible for their high mean pedestrian accident rates, which make them the most hazardous type of residential environment for pedestrians in Edmonton. Equally, the relatively low mean pedestrian accident rates of the planned neighbourhoods, and especially the modified-Radburn and cluster-plan neighbourhoods with superblocks and cluster blocks, can be attributed in large degree to their low street density, low intersection density and limited numbers of entrances/exits. This indicates that Edmonton's planners have achieved a great deal in creating safer residential environments for pedestrians by deliberately reducing the levels of all three variables through their design policies. Even the moderate reduction achieved under Edmonton's replotting schemes in the early 1950s made the modified-grid neighbourhoods generally safer than the pure grid neighbourhoods, both on boundary streets and in neighbourhood interiors.

Reducing the number of neighbourhood entrances/exits is especially significant for minimizing pedestrian accident rates. On boundary streets where most pedestrian accidents occur, fewer neighbourhood entrances/exits mean fewer intersections, which makes traffic control easier and inter-neighbourhood pedestrian trips safer. This partially explains why accident density on boundary streets is much lower for planned neighbourhoods than for unplanned ones, and why the modified-Radburn and cluster-plan neighbourhoods, which have the fewest entry points, have the lowest densities of all.

At the same time, it is not expected that number of intersections (or neighbourhood entrances/exits) is the only environmental factor that accounts for the high incidence of pedestrian ac dents on boundary streets; adjacent land use features and tterns of inter-neighbourhood organization are likely to contribute to this outcome as well. In the first case, for example, the high accident density on the boundary streets of grid neighbourhoods could be expected to be related as well to the commercial ribbons and apartment strips that are sometimes located along them, a possibility that will be investigated in Chapter 8. In the second case, the fact that the proportion of pedestrian accidents on boundary streets is much higher for the independent neighbourhood units than for those of hierarchical organization might be attributed to differences in their inter-neighbourhood organization and community configuration. Independent neighbourhood units, which are rarely if ever self-contained, are usually separated by arterial streets from the adjacent neighbourhoods with which they share service facilities; inter-neighbourhood pedestrian trips are therefore at great accident risk on their boundary streets. In the areas of hierarchical organization, by contrast, boundary streets within communities are "collect-orized", designed to carry intra-community traffic only; those circumscribing communities and carrying city- or district-wide traffic are highly insulated, with reversed peripheral houses.

In addition to the positive influences of low street density, low intersection density and limited numbers of entrances/exits, the relatively low intra-neighbourhood pedestrian accident rates in Edmonton's planned neighbourhoods in general can be attributed to their frequent use of loop streets, culs-de-sac and T-intersections. This is evidenced by the analytical results that culs-de-sac and short loops both have fewer pedestrian accidents than straight access streets, with culs-de-sac being the safest of all; and that T-intersections court fewer pedestrian accidents than either cross- or acute-intersections. In contrast, grid neighbourhoods are characterized by straight access streets and cross-intersections, the least safe forms of both features; accordingly, they have the highest mean intra-neighbourhood pedestrian accident rates of all.

Finally, contrary to a longstanding belief of urban planners, separate footpath networks do not make a significant contribution to the reduction of the overall pedestrian accident rates in the Edmonton neighbourhoods where they are provided. In other words, while both modified-Radburn and cluster-plan neighbourhoods are very safe by Edmonton standards, planners achieved little if any extra advantage by providing extensive footpath networks in the former. As was mentioned in Section 7.4, this may have resulted from the way the original Radburn concept was modified in Edmonton. Nonetheless, it leads to the conclusion that street patterns have much stronger influences on the incidence of pedestrian accidents than footpath networks, and controlling or channelling vehicular traffic is more effective than attempting to move pedestrians from street environments for the sake of their safety.

CHAPTER 8

PEDESTRIAN ACCIDENTS AND LOCAL ENVIRONMENTAL CONFIGURATION

The preceding chapter examined the associations between pedestrian accidents and various features of street patterns and pedestrian networks. This demonstrated that the former at least are correlated with differences in mean pedestrian accident rates, from which it can be inferred that they explain much of the relative safety of the various neighbourhood types as determined in Chapter 6. However, the analyses in Chapter 7 excluded any consideration of land use patterns, another critical design element which is known to vary considerably among neighbourhoods of all types in Edmonton. This is important since the comparisons presented in both Chapter 6 and Chapter 7 were based on averages and generalized data for the different neighbourhood categories. They therefore concealed the effects of local variations in environmental configuration which might explain unusually high occurrences of accidents in certain neighbourhoods. As was described in Chapter 3, Edmonton's neighbourhoods exhibit variations in their detailed forms, especially in terms of the local land use arrangements that might be expected to influence pedestrian movement patterns, both within and between neighbourhoods. It was also revealed in Table 6.1 that the standard deviations of gross pedestrian accident rates largely conform to the ranking of the 5 neighbourhood types, indicating that type 1 or grid neighbourhoods show the greatest within-category variation and type 4 and 5 neighbourhoods the least. The within-category variations were in fact ignored in the analysis of variance in Chapter 6. To complete the analysis of environmental factors in the incidence of pedestrian accidents, then, it is necessary to examine the detailed variations in local configuration to determine (1) if certain features are associated with relatively high accident rates at the neighbourhood level and (2) whether these same features can explain some of the between-category variations, even if they do not occur in all neighbourhoods of their types. These objectives require that neighbourhoods of different types be investigated separately, except for the modified-Radburn and cluster-plan neighbourhoods. In view of the fact that no significant differences were found between them in terms of their street-related features and mean pedestrian accident rates, they are treated together here.

Specifically, this chapter examines all the research hypotheses that relate to the pedestrian safety effects of local environmental configuration. As was explained in Section 4.1.3, these hypotheses were formulated mainly on the basis of a preliminary examination of the maps of pedestrian accident distribution produced for the thesis research, from which the following relations between the incidence of pedestrian accidents and local features of environmental configuration were proposed for substantiation:

11. (a) Grid neighbourhoods that are adjacent to commer-

cial ribbons have higher pedestrian accident rates than those that are not; (b) grid neighbourhoods that are adjacent to apartment strips have higher pedestrian accident rates than those that are not; and (c) grid neighbourhoods with intrusive arterial streets have higher pedestrian accident rates than those without. Here, commercial ribbons refer to the sections of street fronts or block faces that are exclusively lined with retail and commercial service outlets; similarly, apartment strips are defined as the sections of street fronts or block faces that are fully taken up with apartment buildings; and arterials are those streets that are designated as such by the City of Edmonton in its Transportation System Bylaw.

12. Modified-grid neighbourhoods that are adjacent to commercial ribbons, or are adjacent to apartment strips, or have intrusive arterial streets, have higher pedestrian accident rates than others of the same type.

13. Independent neighbourhood units that are bounded by arterial streets with peripheral houses facing on them have higher pedestrian accident rates than those whose peripheral houses are reversed to face internal streets, or those that are mainly bounded by natural barriers.

14. For neighbourhoods with hierarchical structures, those constituting elongated communities with long and relatively straight collector streets have higher pedestrian accident rates than the ones that form compact communities.

15. Neighbourhoods of all types that are adjacent to heavy external traffic generators (i.e. incompatible land uses) experience higher pedestrian accident rates than those that are not.

16. Planned shopping centres generate fewer pedestrian accidents on adjacent arterial streets than unplanned commercial ribbons do. Neighbourhoods adjacent to shopping centres therefore have lower pedestrian accident rates than those on commercial ribbons.

To examine hypotheses 11-15, data on pedestrian accident rates, accident frequencies and a checklist of environmental features were compiled for every study neighbourhood. These data are displayed by neighbourhood type in a series of tables which were analyzed to examine the postulated associations between neighbourhoods with relatively high accident rates and the critical environmental features. While these analyses were a necessary first step, however, they do not explicitly reveal if accidents really happen around the environmental features in question. They are therefore supplemented by detailed area studies to demonstrate the spatial relations between the incidence of pedestrian accidents and the critical environmental features; this is done through close interpretation of large-scale maps of pedestrian accident locations. Pedestrian accident frequencies are useful references here for indicating the actual concentrations of accidents in the study areas, which can then be associated with the critical environmental features. Hypothesis 16 requires a different approach. It is tested by comparing the mean pedestrian accident densities for commercial ribbons and the sections of arterial streets that immediately flank the major district or regional shopping centres.

The chapter is organized into 5 analytical sections. The first two investigate the grid and modified-grid neighbourhoods respectively, to examine hypotheses 11 and 12. The third section looks into the independent neighbourhood units to address hypothesis 13. The fourth investigates the neighbourhoods of hierarchical organization to test hypothesis 14. Hypothesis 15 is examined for each neighbourhood category separately and so is considered in all of the first four sections. Finally, Section 5 corresponds to hypothesis 16.

8.1 Pedestrian Accident Distribution in the Areas of Grid Neighbourhoods (Hypotheses 11 and 15)

It has been established in Chapters 6 and 7 that the grid neighbourhoods in Edmonton constitute the most hazardous type of residential environment for pedestrians, and that their high pedestrian accident rates can be partly attributed to the characteristic features of their grid street patterns. In this section, the safety effects of land use arrangements in grid neighbourhoods, together with other features of their local configuration, will be investigated to supplement Chapter 7 in explaining the high accident rates that have been found there.

Altogether, there are 42 grid neighbourhoods in Edmonton.

They accounted for 24 per cent of the total number of neighbourhoods, but for 63 per cent of the 3034 pedestrian accidents that happened in residential areas in the study period.

Table 8.1 shows the pedestrian accident rates and frequencies for all 42 neighbourhoods. The rates vary considerably, ranging from 39.3 per thousand people to 3.9. The average is 11.7, but the standard deviation is 7.1. The same table also records the occurrence of four critical features of local environmental configuration that have been hypothesized to contribute to a high incidence of pedestrian accidents. These features are strip commercial development, a linear arrangement of multi-family dwellings on busy streets, intrusive arterial roads directly fronted by dwellings, and incompatible land uses that attract external traffic.

On the basis of the information presented in Table 8.1, a line can be drawn between Westmount and Bonnie Doon, dividing the grid neighbourhoods into two groups. The first group comprises 27 neighbourhoods (64 per cent) which have accident rates higher than 9 per thousand and most of which are highly associated with the 4 environmental features; twelve of them have 3 or more of the features and all have at least one. The second group contains 15 neighbourhoods (36 per cent) which have relatively low accident rates and limited associations with the 4 environmental features. Specifically, 74 per cent of the grid neighbourhoods in the first group front on commercial ribbons; 33 per cent front on apartment

Table 8.1
Pedestrian accident rates for the grid neighbourhoods in relation to selected environmental features

Neighbourhood	Accident rates and frequencies	Fronting on commercial ribbon	Fronting on apartment strip	With intrusive arterial road	Adjacent to incompatible land use
McCauley	39.3(156)	Y		Y	Y
Spruce Avenue	34.8 (78)	Y		Y	Y
Central-McDougall	19.7 (97)	Y		Y	Y
Eastwood	18.9 (76)	Y	Y	Y	Y
Canora	18.5 (54)	Y	Y		Y
Queen Alexandra	16.9 (80)	Y			
Prince Charles	16.2 (24)	Y		Y	
Jasper Park	15.6 (21)		Y		
Parkdale	15.3 (52)	Y		Y	Y
Garneau	14.1 (91)	Y		Y	Y
Alberta Avenue	14.0 (84)	Y		Y	
Beacon Heights	13.0 (39)	Y			
Elmwood Park	12.8 (17)		Y		
Highlands	12.1 (32)			Y	
Jasper Place	11.8 (41)	Y	Y	Y	Y
Queen Mary Park	11.8 (67)	Y		Y	
Belvedere	11.6 (57)	Y			Y
Strathcona	11.5 (95)	Y	Y	Y	
Glenwood	11.1 (55)	Y	Y		Y
Ritchie	11.1 (40)			Y	
Inglewood	10.9 (69)	Y	Y	Y	
Virginia Park	10.5 (12)			Y	
McKernan	10.3 (20)				Y
Oliver	9.7(148)	Y		Y	
Montrose	9.5 (29)				Y
Beverly Heights	9.5 (37)	Y			
Westmount	9.1 (54)	Y	Y	Y	
Bonnie Doon	9.0 (37)				Y
Bellevue	8.0 (12)			Y	Y
King Edward Park	8.0 (33)			Y	
Allendale	7.9 (23)				
High Park	7.5 (11)				
Balwin	7.5 (33)				
Riverdale	6.2 (10)				
Westwood	6.1 (20)	Y			Y
Newton	5.8 (17)				
Haseldean	5.1 (17)				
Calder	4.9 (23)				
Delton	4.3 (9)				
Forest Heights	4.1 (18)			Y	
Grovenor	4.1 (9)			Y	
Sherwood	3.9 (7)		Y		
Averages	11.7 (45)				
Standard deviations	7.1 (36)				

* Numbers in brackets are accident frequencies during the study period.
** Letter Y indicates the presence of the particular environmental feature.

strips; 63 per cent are intruded by arterial streets; and 44 per cent are adjacent to incompatible land uses. By contrast, only 7 per cent in the second group front on commercial ribbons; 9 per cent front on apartment strips; 27 per cent are intruded by arterial roads; and 13 per cent are adjacent to incompatible land uses. These figures clearly indicate that neighbourhoods with relatively high pedestrian accident rates have much stronger associations with the 4 environmental features than do neighbourhoods with low accident rates.

To substantiate that the above environmental features are indeed responsible for the high pedestrian accident rates in those grid neighbourhoods where they occur, their relations with accident location patterns are also examined. The first step is based on the information presented in Tables 8.2 and 8.3, which identify all the commercial ribbons and apartment strips in the areas of grid subdivision. Taken together, these two features account for almost 900 accidents, or 24 per cent and 6 per cent respectively of all the accidents that occurred in residential areas. Not surprisingly, then, they have a major impact on accident frequency in the neighbourhoods in which they are located. Thus, the 12 commercial ribbons accounted, in total, for 45 per cent of the 1474 accidents experienced in the 21 grid neighbourhoods that front on them, while the 6 apartment strips, which are adjoined by 10 neighbourhoods, account for 30 per cent of a total 489 pedestrian accidents. (The proportion of accidents on apartment

Table 8.2
Pedestrian accident density on commercial ribbons
Edmonton, 1982-1990

Commercial ribbon	Length (metres)	Average no. of vehicles per day	No. of accidents	Accident density*
** 1. Stony Plain Road (from 149 St to 163 St)	1,620	23,800	92	2.4
** 2. 118 Avenue (from 34 St to 50 St)	1,620	17,900	68	2.3
** 3. 118 Avenue (from 77 St to 106 St)	2,850	16,600	105	2.2
** 4. Whyte Avenue (from 99 St to 109 St)	1,660	31,000	110	2.1
5. 107 Avenue (from 96 St to 117 St)	2,400	21,900	94	1.8
6. Jasper Avenue (from 110 St to 124 St)	1,680	35,400	83	1.4
7. 97 Street (from 105 Ave to 111 Ave)	1,140	20,000	32	1.4
** 8. 124 Street (from Jasper Ave to 107 Ave)	1,350	16,600	31	1.4
** 9. 118 Avenue (from 122 St to 127 St)	630	32,500	25	1.2
**10. 111 Avenue (from 91 St to 101 St)	960	22,400	21	1.0
**11. 101 Street (from 105 Ave to 111 Ave)	1,200	29,000	30	0.9
**12. Fort Road (from 66 St to 137 Ave)	2,100	20,000	29	0.7
Averages	1,600	23,900		1.6

* Accident density is expressed as the number of accidents per 10,000 vehicles (a day) per 100 meters.
**Commercial ribbon on neighbourhood boundary.

Table 8.3
Pedestrian accident density on apartment strips
Edmonton, 1982-1990

Apartment strip	Length (metres)	Average no. of vehicles per day	No. of accidents	Accident density*
** 1. 82 Street (from 118 Ave to Yellowhead Trail)	1,190	29,000	43	1.2
2. 124 Street (from 107 Ave to 118 Ave)	2,100	16,000	38	1.1
** 3. 156 Street (from 95 Ave to 107 Ave)	2,100	20,000	40	1.0
4. 99 Street (from Whyte Ave to Saskatchewan Drive)	1,000	26,000	21	0.8
** 5. 111 Avenue (from 121 St to Groat Road)	1,150	25,000	15	0.5
** 6. 149 Street (from 87 Ave to 99 Ave)	1,870	24,000	15	0.3
Averages	1,570	23,300		0.8

* Accident density is expressed as the number of accidents per 10,000 vehicles (a day) per 100 meters.
** Apartment strip on neighbourhood boundary.

strips would be higher if it were not that some of these neighbourhoods also front on commercial ribbons.) In comparative terms, commercial ribbons are twice as hazardous for pedestrians as apartment strips, as measured by their average accident densities (1.6 vs. 0.8); and two-thirds of the commercial ribbons have higher accident densities than the most hazardous apartment strip. It also follows, since most commercial ribbons and apartment strips are on neighbourhood boundaries, that they are partially responsible for the unusually high pedestrian accident density on the boundary streets of grid neighbourhoods in Edmonton, as was inferred in Section 7.5. However, not all of the commercial ribbons and apartment strips are on neighbourhood boundaries. Some are on arterials that penetrate neighbourhoods and separate local facilities from parts of their intended service areas. It is therefore impossible to isolate the negative effects of intrusive arterial streets from these other features.

The second step in the substantiation procedure is to conduct a detailed examination of actual accident locations in a representative area of grid subdivision in Edmonton. This area (Figure 8.1), which lies immediately north of downtown, includes 9 grid neighbourhoods—Westwood, Delton, Elmwood Park, Alberta Avenue, Eastwood, Parkdale, Spruce Avenue, Central-McDougall and McCauley—and is remarkable for its high concentration of pedestrian accidents. First, it accounted for a total of 589 accidents in the study period, or 19.4 per cent of all the pedestrian accidents in Edmonton's residential areas. Second, 7 of the 9 neighbourhoods have accident rates higher than 9 per thousand, the criterion used to divide the 42 grid neighbourhood into two groups when Table 8.1 was analyzed. All 4 of the critical environmental features are present in this area as well, which makes it an appropriate choice for a case study.

As can be discerned from Figure 8.1, pedestrian accidents are apparently concentrated on the following streets: 107 Avenue, 111 Avenue, 118 Avenue, 82 Street, 95 Street, 96

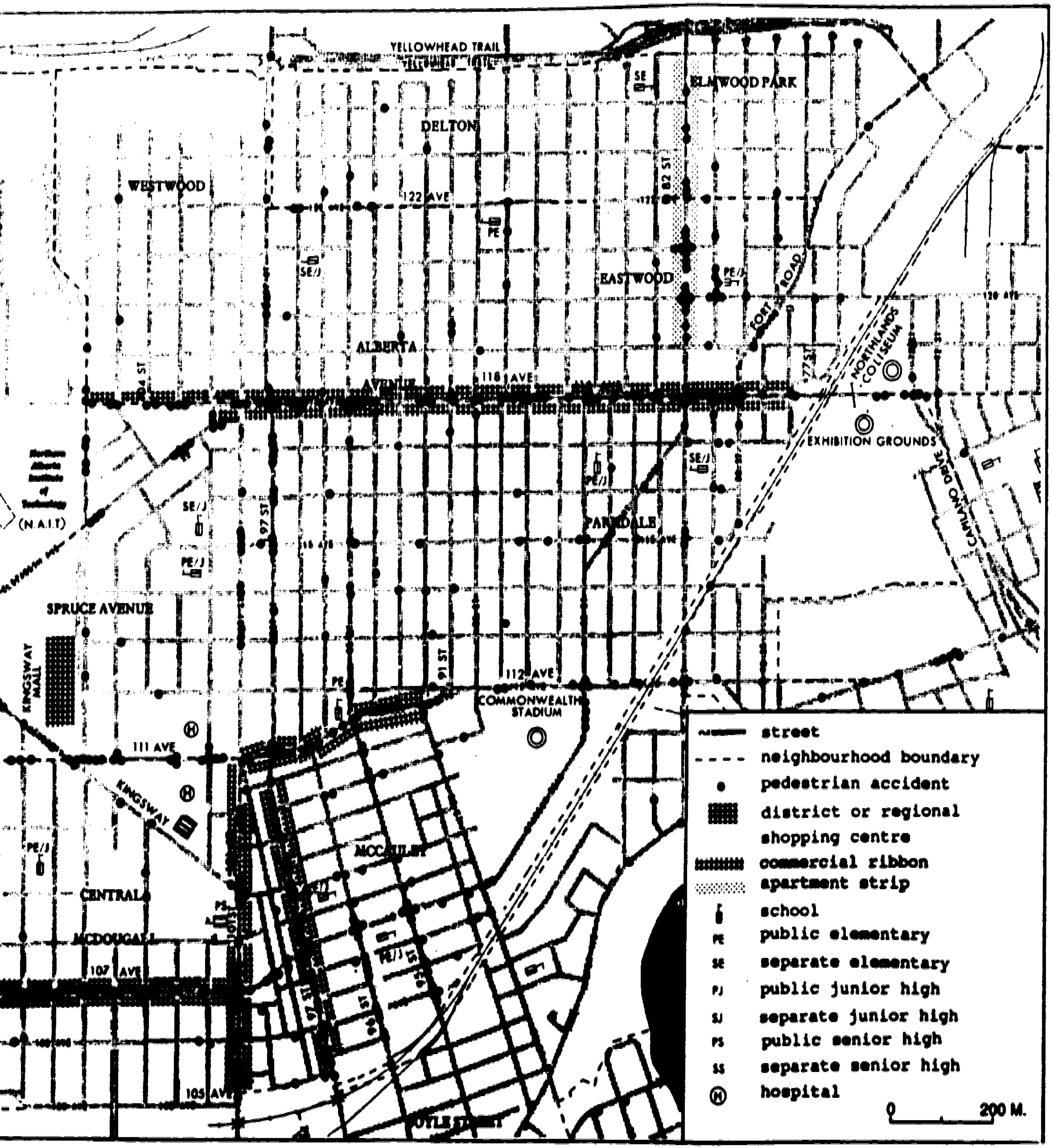

Figure 8.1 Pedestrian accident distribution in a grid residential area north of downtown

Street, 97 Street, 101 Street, and 109 Street. Most of these streets are commercial ribbons; some are apartment strips or intrusive arterial streets; and in some cases, they combine features. Each of these streets will now be discussed in turn with respect to the incidence of pedestrian accidents. Comparisons will also be made wherever possible to further demonstrate that commercial ribbons are more hazardous than other types of streets.

107 Avenue, where it bisects Central-McDougall neighbourhood, is fully lined by shops and service outlets; i.e. it is an intrusive commercial ribbon. Its average traffic volume is 21,900 vehicles per day, yet it also separates many residents from the major neighbourhood service facilities. For example, residential development south of 107 Avenue is mostly in the form of medium-density apartments, which suggests that a considerable proportion of the neighbourhood residents live south of 107 Avenue, whereas all the schools and community service facilities are located in the northern part of the neighbourhood. Students living south of 107 Avenue must cross this busy street at least twice a day at rush hours, contributing further to pedestrian-vehicle conflicts there. Pedestrian accident density on 107 Avenue is a high 1.8/10,000 vehicles/100 metres, which is above average for a commercial ribbon.

111 Avenue is a cross-city traffic corridor, carrying 22,400 vehicles a day on average. Between 91 Street and 101

Street it is a commercial strip. Then, further west, between 101 and 109 Streets, there are three heavy traffic generators (both vehicular and pedestrian): the Royal Alexandra General Hospital (in Central-McDougall), the Glenrose Rehabilitation Hospital (in Spruce Avenue) and Kingsway Garden Mall. Accidents on this section of 111 Avenue are in two apparent clusters: one is around the intersection at 102 Street, between the two hospitals; the other is near the acute intersection with Kingsway, adjacent to Kingsway Garden Mall. Both clusters are in the close vicinity of these incompatible land uses.

97 Street is a primary arterial road channelling traffic between downtown and the suburban residential areas in North Edmonton. Average daily traffic on this street increases from south to north, with 20,000 vehicles between 105 Avenue and 118 Avenue, and 42,000 vehicles from 118 Avenue to Yellowhead Trail. Conversely, pedestrian accident density decreases in the same direction: 1.4/10,000 vehicles/100 metres between 105 Avenue and 111 Avenue, 0.9 between 111 Avenue and 118 Avenue, and 0.1 from 118 Avenue to Yellowhead Trail. The section between 105 and 111 Avenues , which has the highest accident density, is a commercial strip, whereas the next section between 111 Avenue and 118 Avenue is fronted by single family dwellings without service roads. From 118 Avenue to Yellowhead Trail, 97 Street is insulated by a service road on the east side and wire-mesh on the west; both features serve to

restrict pedestrian access and accident density is correspondingly low. Thus, 97 Street is a good demonstration that commercial ribbons contribute more to the incidence of pedestrian accidents than non-commercial streets do, and that well-insulated arterial streets are safer than those without insulation.

101 Street is also an arterial road, linking downtown to 118 Avenue, an east-west cross-city traffic corridor. On average, it carries 29,000 vehicles a day. Between 105 and 111 Avenues, it is a commercial strip forming the boundary between McCauley and Central-McDougall. North of 111 Avenue, it penetrates Spruce Avenue neighbourhood, with no service roads to insulate the flanking houses. As on 97 Street, accident density is higher on the commercial part of 101 Street (0.9/10,000 vehicles/100 metres) than on the section within Spruce Avenue (0.4/10,000 vehicles/100 metres). This demonstrates that while commercial ribbons and intrusive arterial streets are both hazardous for pedestrians, the former generate more pedestrian accidents than the latter, all other things being equal.

95 and 96 Streets between 105 and 111 Avenues also have relatively high concentrations of pedestrian accidents. Until recently, they were both intrusive arterial streets, carrying heavy traffic through the McCauley neighbourhood (an average of 16,000 vehicles a day on 95 Street and 11,000 on 96 Street; 96 Street is now closed for through traffic). Indeed, 95

Street was formally designated as a truck route in 1974 (Edmonton Planning Department, 1981c). It has two negative effects in this neighbourhood. First, it isolates the residences in the eastern part of the neighbourhood from the local service facilities in the western part (such as the public elementary school, the separate elementary/junior high school, and the various shops along 97 Street). Second, it has been increasingly generating pressures on the abutting residential properties for redevelopment to non-residential land uses, especially commercial uses (Edmonton Planning Department, 1981c). It now has many features of a commercial strip. Accident densities are 2.1/10,000 vehicles/100 metres for 95 Street (the truck route) and 1.8 for 96 Street.

118 Avenue has the most extensive linear pattern of pedestrian accidents in the case study area. It is also a commercial ribbon, extending for 2.3 kilometres from 77 Street to 104 Street, with the third highest accident density among all 12 commercial ribbons (see Table 8.2). Pedestrian accidents are especially dense near the intersections with Fort Road, 82 Street and 97 Street. Since these three streets are all arterial roads, pedestrian movement along the commercial strip is constantly interrupted by through traffic in south-north directions.

The linear concentration of accidents along 82 Street in Eastwood and Elmwood Park (an apartment strip) is eye-catching as well, and the accident density there is the highest among all 6 apartment strips in Table 8.2. To the south, 82 Street connects with downtown. To the north, it links up with the Yellowhead Trail freeway and leads to the suburban areas north of Yellowhead Trail. This street was originally laid for light traffic loads. After the suburban areas north of Yellowhead Trail were built up, it was assigned much heavier duties to carry large volumes of through traffic (an average of 29,000 vehicle a day). More importantly, apartment buildings of 3 to 4 storeys are strung along both sides between 118 Avenue and Yellowhead Trail, with building entrances directly facing the street (Figure 8.2). Narrow sidewalks immediately abut vehicle lanes with no planting strips or service roads to protect pedestrians. One of the major neighbourhood service facilities, the Eastwood Elementary/Junior High School, is separated by 82 Street from about two-thirds of its catchment area to the west of the street. Not surprisingly, the pedestrian accident rate for children of 5-14 years in Eastwood is 60 per thousand (as compared with 18.9 per thousand for the neighbourhood population as a whole).

The study area also contains two major incompatible land uses: Commonwealth Stadium and Northlands Coliseum-Exhibition Grounds. Commonwealth Stadium, one of Edmonton's major sports facilities, is surrounded by McCauley, Alberta Avenue and Parkdale. It has a capacity of 60,000 spectators, and so attracts large volumes of traffic when events are held. The streets most affected are 107 Avenue and 111/112 Avenue; the

Figure 8.2 An apartment strip on 82 Street in Eastwood neighbourhood, where buildings are strung along both sides, with building entrances directly facing the street; narrow sidewalks immediately abut vehicle lanes.

two strings of pedestrian accidents along them should be at least partially associated with the traffic generated by the stadium.

Northlands Coliseum-Exhibition Grounds is another heavy external-traffic generator. Regularly, a large number of events are held there every year: over 40 NHL hockey games per season; rock concerts and special shows; 91 days of harness racing and 85 days of thoroughbred racing; and the Exhibition for Klondike Days lasting 10 days each summer (Edmonton Planning Department, 1982b). One study found that the Coliseum-related through traffic was a major transportation problem in the surrounding neighbourhoods (Edmonton Planning Department, 1982a). The negative externalities generated by Northlands Coliseum spill over a large area. In addition to the accident cluster (with 8 accidents) at the southeast corner of Northlands Coliseum (around the junction of 118 Avenue, Capilano Drive and 73 Street), the accidents on 82 Street (an apartment ribbon) and 118 Avenue (a commercial strip) should also partially relate to this incompatible land use, because large volumes of vehicular traffic approach and leave Northlands Coliseum by way of these two arterial streets.

To sum up, commercial ribbons, apartment strips, intrusive arterial streets and incompatible land uses are closely associated with the neighbourhoods with high pedestrian accident rates, as Table 8.1 indicates; and pedestrian accidents tend to cluster around these critical environmental features, especially on commercial ribbons, as Figure 8.1 illustrates. Indeed, all 5 of the commercial ribbons in the study area bear linear concentrations of pedestrian accidents. Relatively speaking, the associations of incompatible land uses with pedestrian accidents are not as clearly revealed as those of the other 3 environmental features, because their negative effects can spill over a large area and they may induce pedestrian accidents beyond their immediate adjacency. Nonetheless, Hypotheses 11 and 15 are generally confirmed by the evidence generated from the analysis of Table 8.1 and the area study. It is revealing as well that Delton is the only neighbourhood in the study area that has none of the 4 critical environmental features; since it also has the lowest pedestrian accident rate and the lowest accident frequency, its patterns give further support to Hypotheses 11 and 15.

8.2 Pedestrian Accident Distribution in the Areas of Modified-Grid Neighbourhoods (Hypotheses 12 and 15)

Table 8.4 lists the pedestrian accident rates and accident frequencies for the 19 modified-grid neighbourhoods, as well as the same 4 environmental features as in Table 8.1. (As a transitional form of development, this is the only other neighbourhood type that is associated with these particular features.) Although the neighbourhoods vary considerably in accident rate, ranging from 2.1 to 17.8 per thousand, their mean rate (5.9) is only half that of the grid neighbourhoods

Table 8.4
Pedestrian accident rates for the modified-grid neighbourhoods in relation to selected environmental features

Neighbourhood	Accident rates and frequencies	Fronting on commercial ribbon	Fronting on apartment strip	With intrusive arterial road	Adjacent to incompatible land use
Prince Rupert	17.8 (15)				Y
Britannia-Youngstown	8.3 (39)	Y	Y		
Athlone	7.8 (17)				
Woodcroft	7.6 (20)				Y
Killarney	7.5 (33)				
Lauderdale	7.0 (18)				
Glenora	6.8 (24)			Y	
Rosslyn	6.1 (20)				
Terrace Heights	6.0 (14)				
Kensington	5.6 (21)				
Pleasantview	4.9 (19)				
Strathearn	4.5 (12)				
Belgravia	4.4 (12)				Y
Windsor Park	4.3 (6)			Y	Y
Parkallen	4.0 (9)				
Rundle Heights	3.0 (12)				
Empire Park	2.8 (12)			Y	
Wellington Park	2.5 (9)				
Avonmore	2.1 (5)				
Averages	5.9 (17)				
Standard deviation	3.4 (9)				

* Numbers in brackets are accident frequencies during the study period.
** Letter Y indicates the presence of the particular environmental feature.

(11.7). The standard deviation of the accident rates is smaller as well (3.4 vs. 7.1 for the grid neighbourhoods), and all but one of the neighbourhoods in this set has accident rates lower than 9 per thousand (which was used to divide the 42 grid neighbourhoods into two groups). The exception is Prince Rupert, and even there the accident rate is not a function of excessive accident frequency but of a relatively small population. Table 8.4 also shows that only 7 of the 19 modified-grid neighbourhoods possess any of the environmental features that were critical to the grid neighbourhoods, and only two (Britannia-Youngstown and Windsor Park) have more than 1 of them.

It will be remembered that the replotting of the undeveloped land within Edmonton's areas of grid subdivision in the early 1950s provided the opportunity for planners to prevent the development of most environmental features that are especially unsafe for pedestrians. Thus, in addition to the modifications to the typical grid street patterns analysed in Chapter 7, arterial streets were generally not allowed to intrude into replotted neighbourhoods and safety measures, such as service roads, were designed into the rare exceptions. More importantly, in light of the conclusions reached in Section 8.1, multi-family dwellings were mostly grouped in clusters and serviced by access streets, rather than strung along arterial streets, and no new commercial ribbons were created. Britannia-Youngstown, which has the highest pedestrian accident frequency and the second highest accident rate among neighbourhoods of this type, is the only one that is associated with a commercial ribbon (on Stony Plain Road; see Table 8.2) and an apartment strip (on 156 Street; see Table 8.3). But even there, the commercial ribbon existed before replotting procedures were implemented.

In conclusion, the 4 environmental features under consideration do not explain the variations in pedestrian accident rates among the modified-grid neighbourhoods, as they do for the grid neighbourhoods. In other words, there is no clear evidence to confirm Hypotheses 12 and 15. On the other hand, it can be concluded that one of the reasons why modified-grid neighbourhoods tend, in general, to have lower pedestrian accident rates than grid neighbourhoods is because these particular environmental features, which bear so strongly on the incidence of pedestrian accidents as Section 8.1 proved, were deliberately avoided when the neighbourhoods were redesigned.

8.3 Pedestrian Accident Distribution in the Areas of Independent Neighbourhood Units (Hypotheses 13 and 15)

Generally speaking, as demonstrated in Chapter 6, independent neighbourhood units (i.e. type 3 neighbourhoods) provide safer pedestrian environments than either grid or modified-grid neighbourhoods. In addition to their lower street density, lower intersection density and fewer entrances and exits, the evident explanation is that those features of local environmental configuration to which high accident rates and accident frequencies among the grid neighbourhoods can be attributed are virtually non-existent in the independent neighbourhood units. In the first place, commercial facilities are mostly grouped to form shopping centres or malls, and they are set back from busy streets with off-street parking bays, rather than being lined along arterial streets in the form of commercial ribbons. Multi-family dwellings are usually grouped in clusters as well, and located within neighbourhoods with access from local streets. The only exception is in Sherbrooke, where apartment buildings align 118 Avenue, but even there they are set back with a service road in front. No arterial streets run through any of the neighbourhood units, except for Crestwood, and although it is common for houses to face the boundary streets, they are set back with service roads as buffers. This is a distinctive design feature of the independent neighbourhood units in Edmonton. In addition, they have few incompatible land uses, except for occasional district or regional shopping centres that generate external traffic. Table 8.5 lists the pedestrian accident rates for all 37 independent neighbourhood units in Edmonton. Compared with the grid and modified-grid neighbourhoods (see Tables 8.1 and 8.4), the independent neighbourhood units have a much lower mean accident rate (3.7 vs. 11.7 and 5.9). Nonetheless, they still accounted for 415 pedestrian accidents during the study period, and these accidents were unevenly distributed. The rates for individual neighbourhoods range from 15.1 to 0; the standard deviation is 2.9.

As determined in Chapter 7, the problem of pedestrian safety in the areas of independent neighbourhood units is most acute on boundary streets: nearly 70 per cent of the pedestrian accidents in this type of neighbourhood occurred on streets that form neighbourhood boundaries (see Table 7.5). This makes inter-neighbourhood functional relations the

Table 8.5
Pedestrian accident rates for the independent neighbourhood units in relation to selected environmental features

Neighbourhood	Accident rates and frequencies	Number of boundaries where peripheral houses face on arterials	Number of boundaries where peripheral houses are reversed from arterials	Number of boundaries that are natural barriers	Immediately adjacent to district or regional shopping centres
Idylwylde	15.1 (27)	4	0	0	Y
Glengarry	10.9 (37)	3	1	0	Y
Elmwood	6.8 (21)	2	1	1	Y
Rideau Park	6.8 (12)	1	2	1	
Argyll	6.7 (6)	1	0	2	
Northmount	5.7 (23)	2	2	0	Y
Kildare	5.6 (17)	3	1	0	Y
Crestwood	5.4 (12)	1	0	3	
West Meadowlark	4.9 (19)	3	1	0	
Sherbrooke	4.4 (11)	3	1	0	
Dovercourt	4.2 (10)	3	1	0	
Kilkenny	4.1 (24)	3	0	1	Y
Evansdale	3.9 (24)	2	1	1	
Fulton Place	3.9 (14)	3	0	1	Y
York	3.9 (15)	2	1	1	Y
Meadowlark	3.6 (10)	4	0	0	Y
Delwood	3.3 (14)	3	1	0	Y
Lynnwood	3.2 (11)	3	0	1	Y
Aspen Gardens	3.2 (6)	1	0	2	
Kenilworth	3.0 (10)	3	1	0	
Parkview	3.0 (11)	2	0	2	
North Glenora	2.9 (6)	0	4	0	
Holyrood	2.8 (10)	4	0	0	Y
McQueen	2.8 (5)	0	4	0	
Duggan	2.6 (13)	1	3	0	
Royal Gardens	2.5 (10)	2	2	0	
Lendrum Place	2.4 (5)	1	2	1	
Mayfield	2.0 (5)	2	2	0	
Ottewell	1.8 (12)	3	1	0	Y
Goldbar	1.4 (4)	1	0	3	
Lansdowne	1.4 (2)	0	1	3	
Malmo Plains	0.7 (2)	1	2	1	Y
Brookside	0.7 (1)	0	0	4	
Laurier Heights	0.6 (2)	2	0	2	
Greenfield	0.6 (3)	1	3	0	
Capilano	0.3 (1)	1	0	3	
Grandview Heights	0.0 (0)	0	1	3	
Average	3.7 (11)				
Standard deviation	2.9 (8)				

* Numbers in brackets are accident frequencies during the study period.
** Letter Y indicates the presence of the particular environmental feature.

central concern for the investigation of the associations between local environmental configuration and pedestrian accidents in this particular type of residential environment.

According to neighbourhood unit theory, a neighbourhood unit should normally be bounded by either arterial streets or natural barriers (such as ravines, woodlands and open spaces). This is exactly what was followed in the development of Edmonton's neighbourhood units in the 1950s and early 1960s. But while most of them have a public elementary school within their territory, they are far from self-contained with regard to other services and facilities, such as public high schools, separate elementary/high schools, and shopping facilities. In most cases, adjoining neighbourhoods that share these service facilities are separated by arterial roads carrying heavy through traffic. And although it is not inappropriate for the shared facilities to be located on the periphery of the host neighbourhood, it is surely unsafe to have them on one side of an arterial street when an important part of their service area is on the other.

To examine the propositions that (1) independent neighbourhood units that are bounded by arterial streets with houses facing on them have higher pedestrian accident rates than those with other forms of boundaries (Hypothesis 13), and that (2) independent neighbourhood units adjacent to heavy external traffic generators have higher accident rates than those that do not have this feature (Hypothesis 15), Table 8.5

was prepared. From this it can be seen that those neighbourhoods that have relatively high accident rates for their type are mainly bounded on three or even four sides by arterial streets with facing houses. They also tend to be associated with district or regional shopping centres, which generate considerable amounts of external traffic. Neighbourhoods that have lower accident rates are not necessarily more self-contained, however. Rather, they tend to have one or more of the following three features: (1) they are largely bounded by open areas (such as Grandview Heights, Brookside and Lansdowne; see Figure 8.3); (2) their peripheral houses are reversed to face internal streets with limited access to the arterials (such as McQueen, North Glenora, Lendrum, Malmo Plain and Greenfield; see Figure 8.4); or (3) there are no district or regional shopping centres in their close vicinity. Specifically, 12 (57 per cent) of the 21 neighbourhood units that have accident rates equal to or higher than 3 per thousand are bounded on 3 or more sides by arterial streets with peripheral houses facing on them; and 11 (52 per cent) are adjacent to district or regional shopping centres. In contrast, only 2 (13 per cent) of the 16 neighbourhood units with accident rates below 3 per thousand are bounded on 3 or more sides by arterials without reversed frontage (and even these two neighbourhoods, Holyrood and Ottewell, have relatively high accident frequencies); and only 3 (19 per cent) are adjacent to district or regional shopping centres (includ-

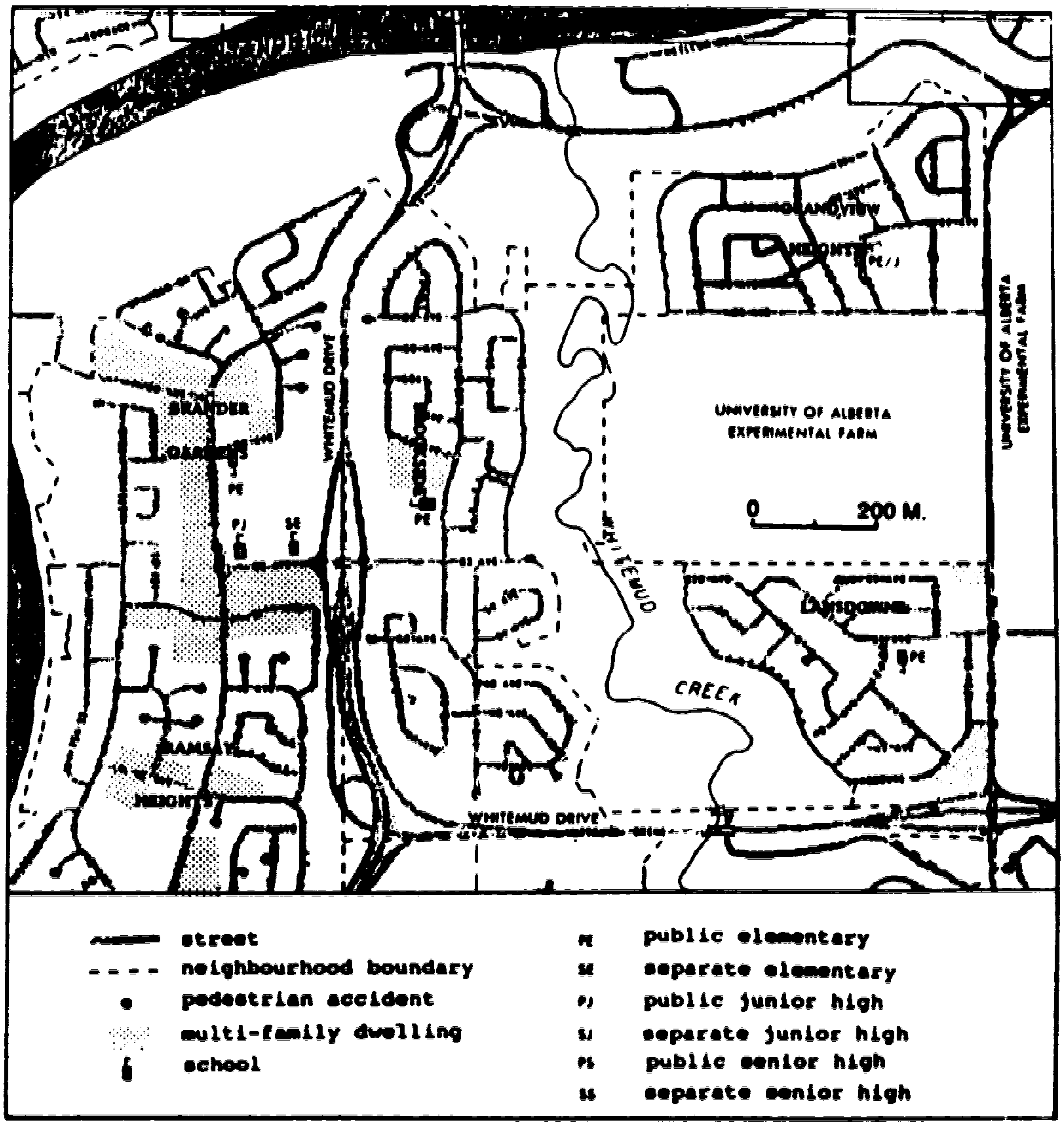

Figure 8.3 Isolated neighbourhoods of Grandview Heights, Brookside and Lansdowne, largely bounded by the Whitemud Creek, the University of Alberta Experimental Farm and the depressed Whitemud Drive freeway.

Figure 8.4 107 Avenue on the boundary of McQueen neighbourhood, with reversed frontage. Reversing the flanking houses does not in itself reduce inter-neighbourhood pedestrian trips, but it reduces the opportunities for jaywalking.

ing both Holyrood and Ottewell). This means that Hypotheses 13 and 15 are largely confirmed, though not all relatively high accident rates in independent neighbourhood units can be explained by these features.

To illustrate the accident hazards of boundary streets in areas of neighbourhood unit development, a sample area is examined in detail. This examination also demonstrates the negative effects that district and regional shopping centres can have on pedestrian safety in otherwise highly planned residential areas.

The case study area (Dickinsfield in north Edmonton), which is illustrated in Figure 8.5, consists of 9 neighbourhoods. Seven of them are independent neighbourhood units: Evansdale, Kilkenny, Northmount, Kildare, York, Glengarry and Delwood; the other two, McLeod and Casselman, form a hierarchically organized unit. The independent neighbourhood units in this area have accident rates that range from 3.3 per thousand population to 10.9 and all but one of them is above the average for this type of neighbourhood.

In terms of educational facilities, each of the independent neighbourhood units has a public elementary school (largely centrally located), but only 4 of them have a separate elementary school. In addition, there are only 4 junior high schools (2 public and 2 separate) and 2 senior high schools (one for each school system) in the study area. In short, the independent neighbourhood units were designed to

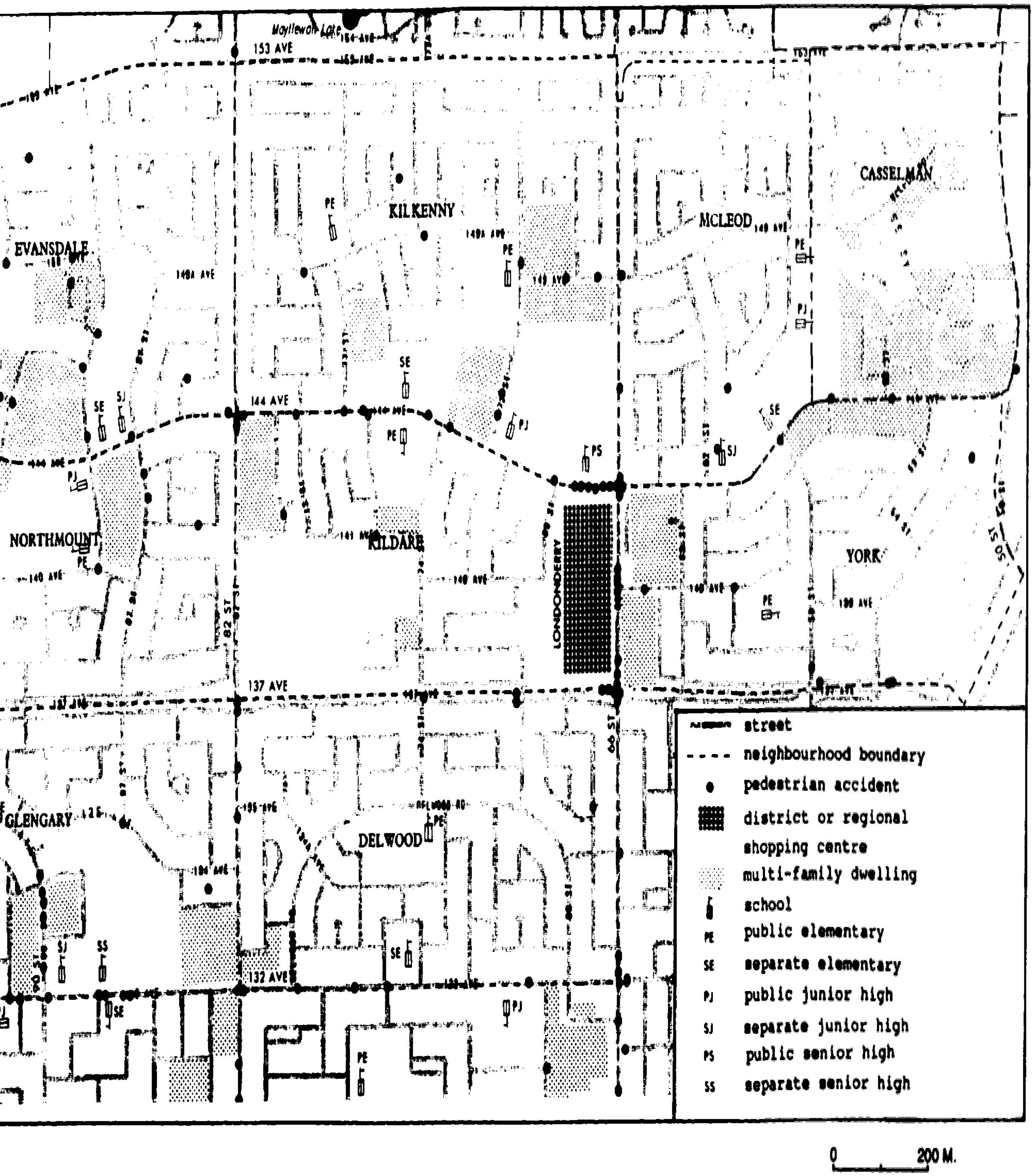

Figure 8.5 Pedestrian accident distribution in an area of independent neighbourhood units in north Edmonton (Dickinsfield)

be self-contained only for public elementary education. Most separate school students, and most students attending high schools in either system, have to travel beyond their neighbourhood boundaries.

With regard to shopping facilities, only Evansdale and Kilkenny have a neighbourhood shopping centre. However, the area also includes three regional shopping centres: Londonderry Mall (in Kildare), Northwood Mall (in Glengarry) and North Town Mall (in Northmount). This is an unusual concentration and might be expected to generate large volumes of external traffic.

For the most part, the 7 independent neighbourhood units are bounded by arterial streets carrying high volumes of traffic (see Table 8.6). Except for 97 Street (between 137 and

Table 8.6
Average weekday traffic on the boundary streets of the independent neighbourhood units in Figure 8.5, 1982-1990

Boundary street	Average no. of vehicles per weekday
1. 97 Street (from 132 Ave to 153 Ave)	38,000
2. 137 Avenue (from Fort Road to 97 St)	26,000
3. 66 Street (from 132 Ave to 153 Ave)	19,000
4. 82 Street (from 132 Ave to 153 Ave)	17,000
5. 144 Avenue (from 50 St 97 St)	14,000
6. 132 Avenue (from 66 St to 97 St)	9,000
Average	20,500

153 Avenues) and 137 Avenue, all the boundary streets have facing houses with service roads. Altogether, the 7 independent neighbourhood units experienced 154 pedestrian accidents, of which 64 per cent occurred on the boundary streets listed in Table 8.6. The main concentrations were on 132 and 144 Avenues and around the three major shopping centres. It is also significant that 56 per cent of all the accidents involved school-aged children (5-19 years), especially along 132 Avenue and 144 Avenue where there are a number of separate schools and public high schools, situated to serve neighbourhoods on both sides of the streets. Two strings of pedestrian accidents can be discerned there, accounting for 47 accidents altogether, of which 31 (66 per cent) involved school-aged children. There were fewer accidents on 137 Avenue between Londonderry Mall and Northwood Mall, mainly because the flanking houses along this section of 137 Avenue are reversed to face internal streets and access to the street is limited to a few designated crossing points.

Londonderry Mall is located on the west side of 66 Street between 137 Avenue and 144 Avenue. Immediately adjacent to the mall are single-family houses on the south side of 137 Avenue, multi-family dwellings on the east side of 66 Street (with service roads in front of them), and the M. E. Lazerte (Public) Senior High School on the north side of 144 Avenue. All are potential origins of pedestrian shoppers. Around the mall, two clusters of pedestrian accidents stand out: one is at the intersection of 137 Avenue with 66 Street (8 accidents); the other is on 144 Avenue in front of the senior high school (11 accidents). The junction of 137 Avenue and 66 Street is a cross-intersection, the most hazardous type of intersection for pedestrians, and although it is fully controlled with signal lights, vehicle-pedestrian conflicts are still intense. The second cluster on 144 Avenue is largely attributed to the location of the senior high school in relation to the shopping mall. The school's main entrance on 144 Avenue faces Londonderry Mall's north entrance. It was observed on site that many students from the high school visited the mall after class in the afternoon (probably during lunch time too). There is a marked crosswalk in front of the school entrance, but many pedestrians did not use it. Jaywalking is a problem there.

Northwood Mall and North Town Mall are both located at the junction of 137 Avenue and 97 Street, separated only by an arterial street (137 Avenue). This arrangement of two large shopping centres does not conform to any principle of land use planning. Their contributions to the relatively poor accident records of the adjoining neighbourhoods of Glengarry and Northmount are three-fold. First, they draw large amounts of vehicular traffic onto nearby boundary streets such as 137 Avenue and 97 Street. Second, they induce pedestrian movement across 137 Avenue, interweaving with the heavy and fast-moving traffic stream. Third, the negative effects of Northwood Mall spill over to the internal streets of its host neighbourhood, Glengarry, which has the highest pedestrian accident frequency and the second highest accident rate of all the independent neighbourhood units. Because the vehicle entrance to the rear parking lot of Northwood Mall is located on 135 Avenue, a collector street directly serving abutting dwellings, mall-related traffic is significant within Glengarry. Up to 10,500 vehicles a day have been recorded by the City's Transportation Department, which does not monitor traffic volumes on collector streets unless safety becomes a concern for local residents. The string of pedestrian accidents on 135 Avenue and 90 Street (which is part of the collector street and fronted by multi-family dwellings and playgrounds) must surely be related to the unusual traffic situation created by the mall. North Town Mall does not cause similar problems on the internal streets of Northmount. This can be explained by the differences in local environmental configuration. First, North Town Mall has no rear parking lot, so all customer vehicles concentrate in front of the shopping centre. Second, there are no entrances to Northmount from 97 Street, which greatly reduces the opportunities for through traffic.

This area analysis provides concrete evidence that where local service facilities are oriented towards more than one neighbourhood unit and their intended service areas are separated by arterial streets, pedestrians (especially school-aged children) are indeed subject to accident hazards on boundary streets, especially those that have facing houses (such as 132 and 144 Avenues), even with service roads. The case study also demonstrates that regional and district shopping centres, if poorly insulated from their host neighbourhoods (in the case of Northwood Mall) or if located with schools or multi-family dwellings opposite them on the same arterial street (such as Londonderry Mall), do generate a relatively high incidence of pedestrian accidents in their vicinity. It seems that where large volumes of traffic move at high speed and frequent cross-street pedestrian movement is necessary, the combination of service roads and controlled crossings is inadequate for pedestrian safety. The evidence provided by this area study therefore complements the analysis of Table 8.5 to support Hypotheses 13 and 15.

8.4 Pedestrian Accident Distribution in the Areas of Hierarchical Organisation (Hypotheses 14 and 15)

It will be remembered that neighbourhoods planned as units in hierarchical structures (types 4 and 5) have the lowest pedestrian accident rates of all, and that the difference between them and the independent neighbourhood units mainly shows up on their boundary streets, as was indicated in Chapters 6 and 7.

Generally speaking, two design features make the boundary streets of the hierarchically organised neighbourhoods relatively safe. First, individual neighbourhoods, while still centred on a public elementary school, were deliberately grouped to form communities in consideration of other local service facilities that need the population of more than one neighbourhood to support them, such as separate elementary schools, high schools from both school systems and sometimes shopping centres. Normally, only communities are bounded by arterial roads that carry inter-district through traffic. Within a community, component neighbourhoods are usually separated by collectorized streets, which were designed to carry intra-community traffic only. Communities are functionally more self-contained than the independent neighbourhood units. Although inter-neighbourhood pedestrian trips are still necessary, pedestrian movement within communities dcas not involve crossing heavily trafficked arterial streets.

Second, service roads, which are a common design feature on the boundary streets of independent neighbourhood units in Edmonton, are rarely used in community design. Residential buildings near arterial streets are mostly reversed and separated from the roads with either fences or earth berms. Pedestrian access points on the arterial roads are strictly limited, and opportunities for jaywalking are greatly reduced. In addition, few pedestrian generators (such as schools and shopping facilities) are located along arterial streets, unlike the situation on 132 and 144 Avenues in Figure 8.5.

Although the range of pedestrian accident rates is wide among the hierarchically planned neighbourhoods (from 9.1 to

0; see Table 8.7), the standard deviation is only 1.6. This is because the majority of the neighbourhoods (78 per cent) have low accident frequencies (fewer than 10 accidents in the nine-year study period). Moveover, the accidents are scattered over several streets and have few obvious concentrations. Nonetheless, as assumed in Hypotheses 14 and 15, two features of local environmental configuration are associated with those neighbourhoods that have relatively high accident rates for their types: (1) elongated communities, in which collector streets tend to favour speeding; (2) incompatible land uses that draw external traffic. At first sight, community shape appears to have weak associations since the Y's representing "elongated community" are widely scattered over the column in Table 8.7. Yet, if the average accident rate (1.9) is used as a breaking point, Table 8.7 reveals that 52 per cent of the neighbourhoods with above-average accident rates belong to elongated communities, versus 26 per cent with below-average accident rates. Incompatible land uses seem to have stronger associations, since all but one of the neighbourhoods that adjoin them have above-average accident rates; the exception is Belmead, a neighbourhood that adjoins West Edmonton Mall.

Unlike collector streets in independent neighbourhood units which seldom carry through traffic, the collector streets in type 4 and 5 neighbourhoods normally carry some through traffic from or to other neighbourhoods of the same community. Moreover, if the communities are elongated their

Table 8.7
Pedestrian accident rates for the neighbourhoods of hierarchical organization in relation to selected environmental features

Neighbourhood	Accident rates and frequencies	Forming elongated community	Immediately adjacent to incompatible land use
Summerlea	9.1 (12)	Y	Y
Abbotts Field	5.4 (9)		
Lee Ridge	4.8 (15)		
Thorncliff	4.8 (18)	Y	Y
Homesteader	4.7 (17)	Y	
Tweddle Place	4.2 (15)		
Kameyosek	3.7 (10)		Y
Tipaskan	3.4 (11)		Y
Richfield	3.4 (12)		
La Perle	3.0 (14)	Y	
Caernavon	2.9 (13)	Y	
Menisa	2.7 (7)		
Brander Gardens	2.6 (6)		
Ormsby Place	2.5 (9)	Y	
Overlanders	2.5 (6)	Y	
Pollard Meadows	2.3 (8)		
Meyonohk	2.2 (7)		Y
Carlisle	2.1 (9)	Y	
Callingwood North	2.0 (5)	Y	
Belmont	2.0 (8)		
Dunluce	1.9 (13)	Y	
Meyokumin	1.8 (6)		
Mairsine	1.8 (5)		
Lorelei	1.7 (9)	Y	
Sweet Grass	1.6 (5)		
Michaels Park	1.6 (4)		
Aldergrove	1.4 (7)	Y	
Sakaw	1.4 (5)		
Lymburn	1.3 (5)	Y	
Sifton Park	1.2 (3)		
Belmead	1.2 (5)	Y	Y
McLeod	1.2 (3)		
Bannerman	1.2 (4)		
Rio Terrace	1.2 (2)		
Beaumaris	1.1 (3)	Y	
Baturyn	1.1 (6)	Y	
Hillview	1.1 (4)		
Ekota	1.1 (4)		
Blue Quill	1.0 (4)		
Ermineskin	1.0 (3)		
Casselman	1.0 (3)		
Gariepy	0.8 (2)	Y	
Fraser	0.8 (2)		
Oleskiw	0.8 (1)		
Blue Quill west	0.8 (1)		
Satoo	0.8 (3)		
Callingwood South	0.8 (3)	Y	
Steinhauer	0.7 (2)		
Kernohan	0.7 (2)		
Ramsay Heights	0.6 (2)		
Westridge	0.6 (1)		
Greenview	0.6 (2)		
Skyrattler	0.4 (1)		
Kehewin	0.0 (0)		
Quesnell Heights	0.0 (0)		
Patricia Heights	0.0 (0)		
Average	1.9 (6)		
Standard deviation	1.6 (4)		

* Numbers in brackets are accident frequencies during the study period.
** Letter Y indicates the presence of the particular environmental feature.

collector streets are relatively straight with open vistas, which encourages drivers to speed.

Figure 8.6 shows an elongated community consisting of three neighbourhoods: Homesteader, Overlanders and Canon Ridge. Both Homesteader and Overlanders have pedestrian accident rates that are above average for their type. (Canon Ridge was developed after 1982, and therefore is not included in Table 8.7). This community is bounded by a railroad on the south and a ravine on the north. There are no arterial roads on the boundaries of the community to channel fast-moving traffic. Consequently, Hermitage Road, which extends for 3.1 kilometres with open vistas, has become an alternative for through traffic. In Homesteader, the schools (a public elementary and a separate elementary) and the community shopping centre are all located on the south side of Hermitage Road. Multi-family dwellings are mostly on the north side of the road. During my field observations, pedestrians were seen crossing this collector street frequently, not only at intersections with designated crosswalks but also at mid-block locations where no signals, signs or pavement marks exist. Near 50 Street, townhouses immediately front on Hermitage Road on the north side, without service roads (Figure 8.7). This can be regarded as acceptable practice since Hermitage Road is a collector street, not an arterial. Yet pedestrians are still threatened by through traffic moving at 50 km per hour (which is the legal speed limit). The string of pedestrian accidents

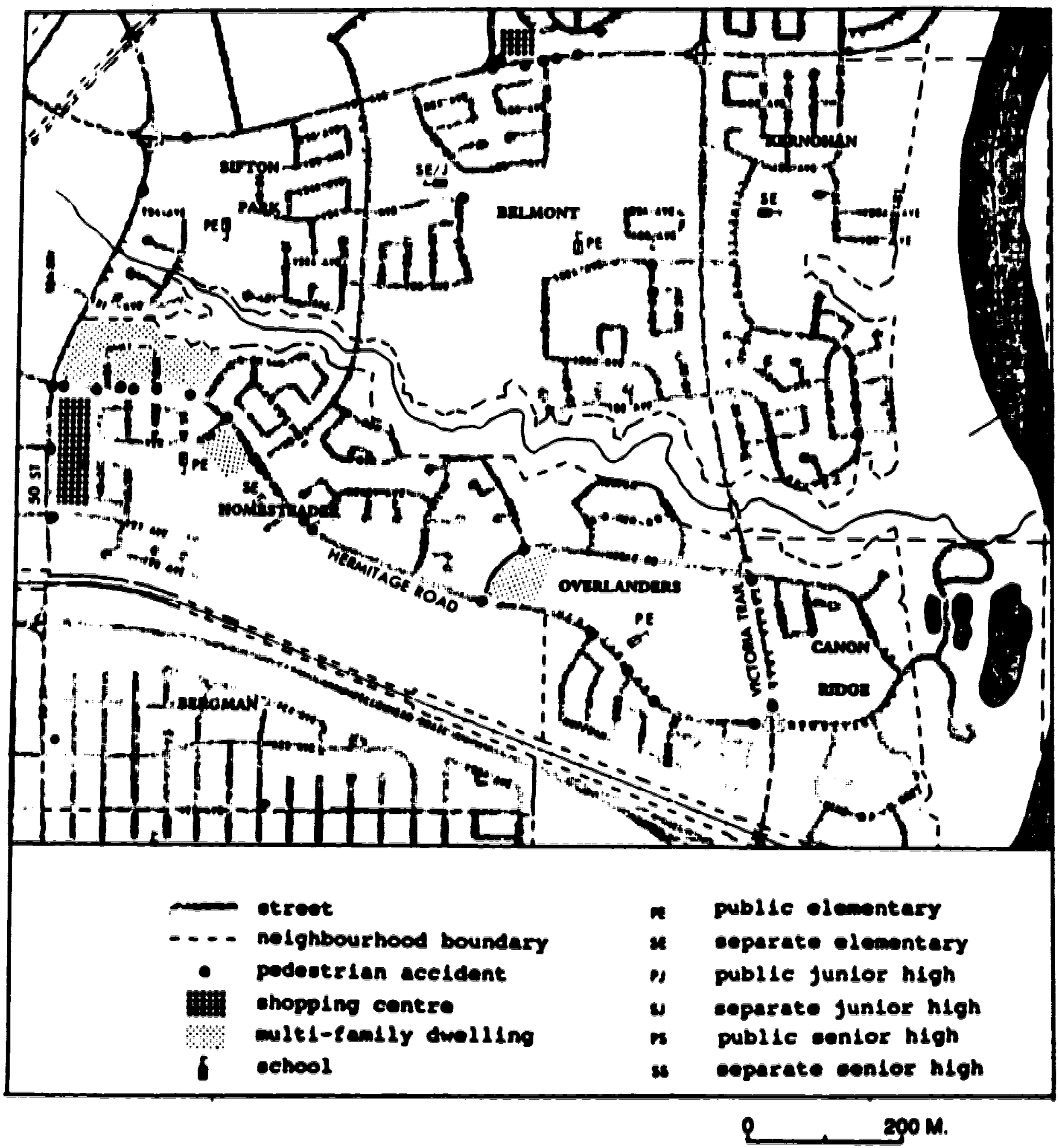

Figure 8.6 Pedestrian accident distribution in the elongated community of Homesteader in Clairview

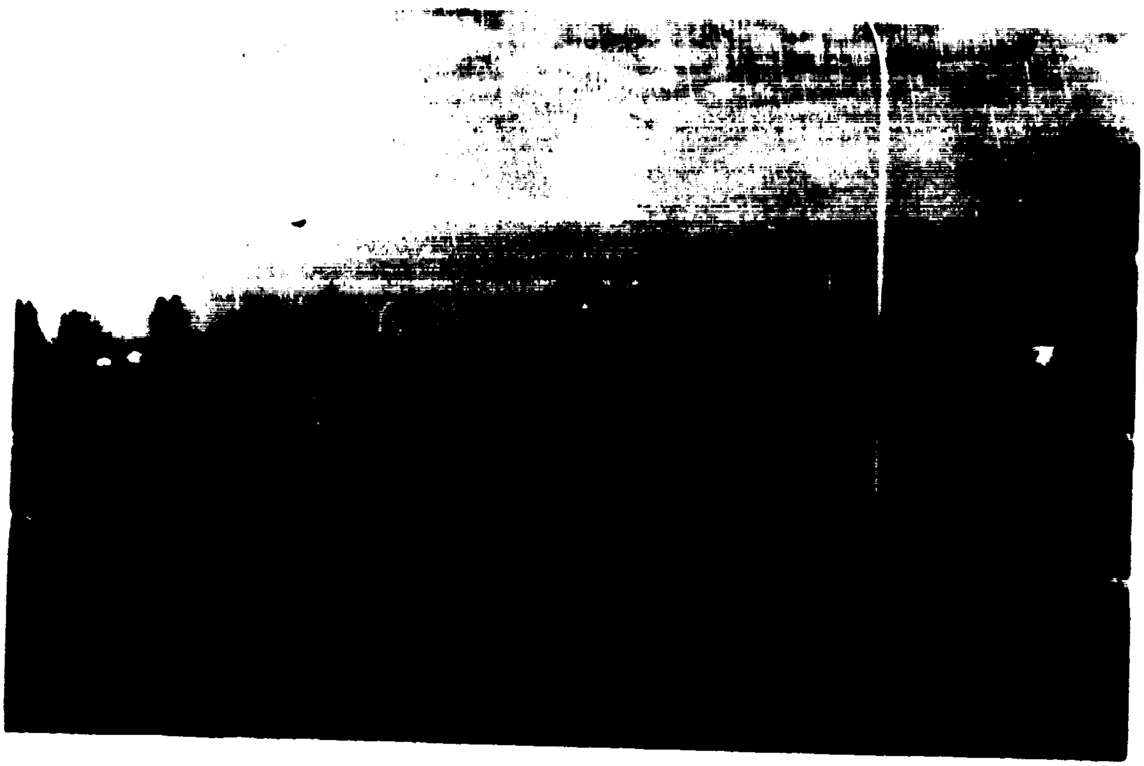

Figure 8.7 Townhouses front on Hermitage Road in Homesteader, without service roads.

on Hermitage Road is indicative of the pedestrian-vehicular conflicts there.

Figure 8.8 shows another elongated community in the Castle Downs district in north Edmonton. Three neighbourhoods are included, all of which have above-average pedestrian accident rates. Within the community, the collector street (139 Avenue—121 Street—162 Avenue) extends for 4.2 kilometres, with a speed limit throughout of 50 km per hour. On the east side of 121 Street between 145 and 152 Avenues is a superblock with an array of neighbourhood service facilities, including two schools, two shopping centres and a neighbourhood park. On the west side of 121 Street are townhouses as well as single-family dwellings. Although marked crosswalks with erected signs or amber flashers are in place at almost every intersection, jaywalking was observed. A string of accidents, although relatively dispersed, is evident along 121 Street.

Two structures in the areas of hierarchical organization are regarded as incompatible land uses: one is West Edmonton Mall, the other is Grant MacEwan Community College in Mill Woods. Both are situated within the boundaries of their host communities, but are oriented toward much larger service areas and so draw external traffic. The patterns of pedestrian accident distribution around these two facilities are indicative of their negative effects on pedestrian safety.

The case of West Edmonton Mall is illustrated in Figure 8.9 which shows the northern portion of the comprehensively-

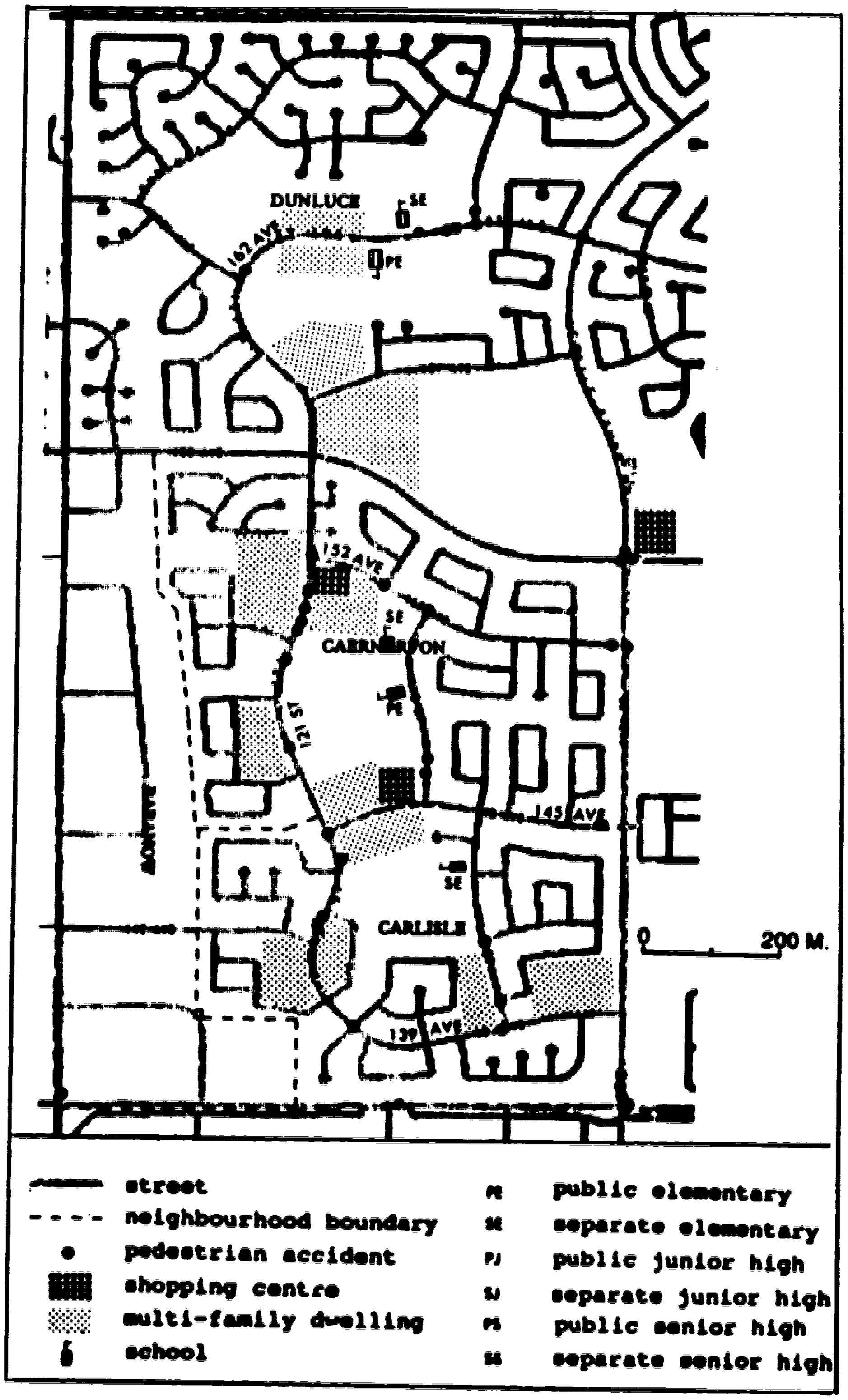

Figure 8.8 Pedestrian accident distribution in the elongated community of Caernarvon in Castle Downs

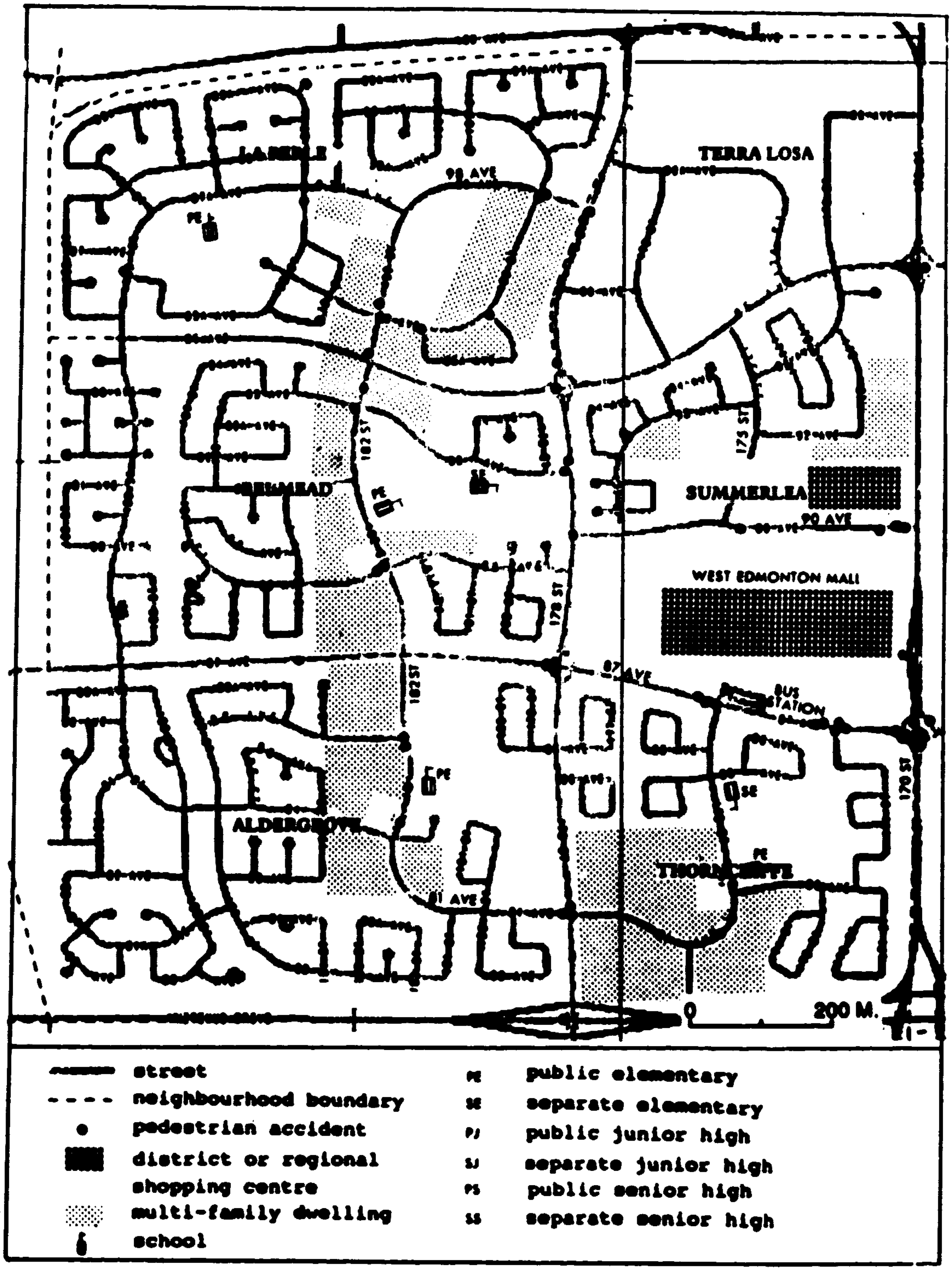

Figure 8.9 Pedestrian accident distribution in the northern portion of West Jasper Place district. This area has been badly interrupted by the intrusion of West Edmonton Mall.

planned suburb of West Jasper Place. The mapped area was intended to comprise six neighbourhoods organized into two communities, but that plan has been disrupted by the construction of West Edmonton Mall, which was added after the development of the adjacent neighbourhoods had begun (Smith, 1991). Among the consequences, Summerlea was reduced to half its planned size, the continuity of the collector loop in the eastern tier of neighbourhoods was broken, and traffic flow patterns in the surrounding area have changed substantially. Everyday, including weekends and holidays, West Edmonton Mall attracts tens of thousands of vehicles from all over the city and from surrounding towns and municipalities. This puts heavy burdens on the neighbourhood boundary streets in this residential area. According to the City's Transportation Department, the average weekday traffic is 27,000 vehicles on 87 Avenue, 33,100 on 178 Street, 22,000 on 90 Avenue and 49,900 on 170 Street.

While the development of West Edmonton Mall has caused the adjacent streets to become much busier than they were planned to be, there are two reasons to believe that local pedestrians still cross them frequently. First, West Edmonton Mall is not just a shopping centre, but a major recreation and entertainment centre (Hopkins, 1991; Jackson, 1991). It serves the interests of all ages, and draws pedestrians from the nearby neighbourhoods within walking distance (Wickert, 1993). Second, these neighbourhoods were developed in phases, and local service facilities were to be provided as the population grew to require them. Even now, Summerlea does not have a public elementary school, and no high school of any kind has been built in any of the neighbourhoods north of Whitemud Drive. The closest high schools are in Elmwood and West Meadowlark Park (which are located east of Thorncliff and West Edmonton Mall respectively, across 170 Street). Those students who live in West Jasper Place and walk to the high schools in Elmwood and West Meadowlark Park, all have to cross one or more of the heavily trafficked streets around West Edmonton Mall, especially the intersection of 87 Avenue with 170 Street, where a cluster of 9 accidents stands out (see Figure 8.9); 5 involved school-age children .

On the other hand, the pedestrian-vehicular conflict in the vicinity of West Edmonton Mall might have been even more intense if the surrounding neighbourhoods had not been designed for limited access. Thorncliff has only two entry/ exit points on 87 Avenue, as does Belmead on 178 Street. This reduces the number of intersections. Besides, all the houses along 87 Avenue and 178 Street are reversed to face the internal streets, otherwise the possibility of jaywalking around West Edmonton Mall would be much higher.

Above-average pedestrian accident rates are also registered in Tipaskan, Kameyosek and Meyonohk, all belonging to Lakewood Community in Mill Woods (see Figure 8.10). Here, there are two interruptive features of note. One is 28 Avenue,

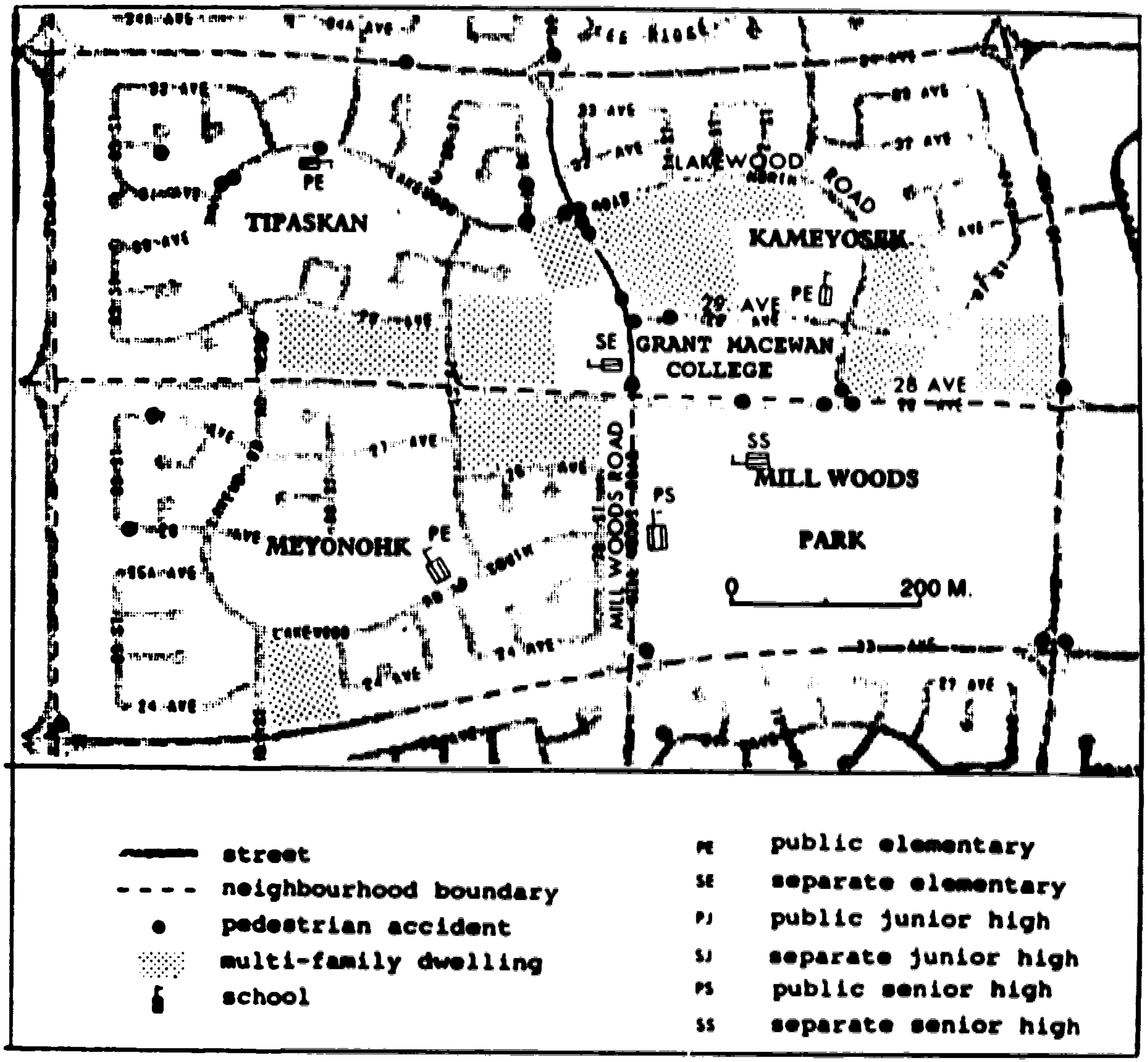

Figure 8.10 Pedestrian accident distribution in the community of Lakewood in Mill Woods. Grant MacEwan Community College is situated in the centre of the community.

which cuts through the community as an arterial road; the other is the Mill Woods campus of Grant MacEwan Community College. 28 Avenue was initially laid down as a potential route for rapid rail transit (see Figure 3.7). The LRT system has not been extended to Mill Woods yet, but 28 Avenue has nonetheless become a major traffic route. The Grant MacEwar campus, which is sited within Kameyosek, takes students from a wide area of Edmonton due to some unique programs it offers. As it is now, the college accommodates 800 full-time students with 50 permanent teaching staff. The campus itself provides 350 off-street parking spaces, but the entrances to the parking lot are from streets that are internal to Kameyosek (i.e. Lakewood Road and 29 Avenue). This means that all vehicles entering and leaving the campus travel within Kameyosek. Of the 28 pedestrian accidents that occurred in this community during the study period, 12 were in the relative adjacency (within two blocks) of the Grant MacEwan campus.

In summary, Table 8.7 and the area analyses do provide evidence that neighbourhoods forming elongated communities tend to have higher pedestrian accident rates than is normal for their type, and the collector streets in these communities tend to have linear patterns of pedestrian accidents. There is evidence that planned neighbourhoods that are adjacent to incompatible land uses experience higher accident rates as well. At the same time, some neighbourhoods that form compact communities and have no incompatible land uses in their close vicinity (such as Abbotts Field, Lee Ridge, Tweddle Place and Richfield), show higher accident rates than others that form elongated communities (such as Lymburn, Beaumaris, Gariepy and Callingwood South). There are no obvious environmental features to explain these differences. Since patterns of accidents are indeterminate in these neighbourhoods, largely because accident frequencies are low, they were more likely to have happened "accidently" or randomly, and should be attributed to behavioural factors. Hypotheses 14 and 15 are therefore largely confirmed, though with exceptions.

8.5 Comparison of Shopping Centres with Commercial Strips for Pedestrian Safety Effects (Hypothesis 16)

One conclusion that emerges repeatedly from the above discussions is that pedestrian accidents are closely associated with commercial land uses in both unplanned and planned residential areas. At the same time, it is generally presumed that shopping centres generate fewer pedestrian accidents than commercial ribbons do. To test that presumption, as expressed in Hypothesis 16, the mean pedestrian accident density for the sections of arterial streets that immediately flank 10 major district or regional shopping centres (and their affiliated parking lots) is calculated and compared with that for the 12 commercial ribbons (see Tables 8.8 and 8.2). The result shows that the mean accident density around shopping centres is 56 per cent lower than that for the 12 commercial ribbons (0.7

Table 8.8
Pedestrian accident density on the arterial streets surrounding 9 major shopping centres in Edmonton, 1982-1990

Shopping centre	Street	Length (metres)	Average No. of vehicles per day	No. of accidents	Accident density*
Londonderry Mall	137 Ave	430	25,300	9	0.9
	144 Ave	240	14,000	10	3.0
	66 St	580	20,000	11	0.9
Northwood Mall & North Town Mall	137 Ave	420	28,500	14	1.2
	97 St	520	35,000	15	0.8
Meadowlark Mall	87 Ave	360	19,700	10	1.4
	156 St	380	17,000	3	0.5
Bonnie Doon Mall	Whyte Ave	210	32,000	7	1.0
	83 St	720	20,000	33	2.3
Southgate Mall	51 Ave	330	20,000	2	0.3
	111 St	600	29,000	4	0.2
Capilano Mall	98 Ave	500	10,400	1	0.2
	Terrace Rd	660	12,400	2	0.2
	50 St	330	21,600	2	0.3
Heritage Mall	111 St	510	29,000	2	0.1
	23 Ave	450	20,000	1	0.1
West Edmonton Mall	170 St	600	49,900	3	0.1
	178 St	360	33,000	3	0.3
	87 Ave	1050	27,000	13	0.5
	90 Ave	960	22,000	4	0.2
Kingsway Mall	106 St	600	19,000	4	0.4
	109 St	300	25,000	5	0.7
	112 Ave	360	18,000	4	0.6
Westmount Mall	135 St	540	7,700	3	0.7
	Groat Rd	540	25,000	15	1.1
	111 Ave	240	27,000	6	0.9
Averages		492	23,370		0.7

* Accident density is expressed as the number of accidents per 10,000 vehicles (a day) per 100 meters.

versus 1.6), indicating that the shopping centre is indeed a safer form of commercial land use organization. Hypothesis 16 is thus explicitly proved. This finding also implies that neighbourhoods adjacent to district or regional shopping centres should have lower pedestrian accident rates than those fronting on commercial ribbons. This can be supported by the information presented in Tables 8.1, 8.4, 8.5 and 8.7. For instance, the average pedestrian accident rate for the neighbourhoods fronting on the 12 commercial ribbons is 15 per thousand people, as compared with 4.7 for the neighbourhoods immediately adjacent to the 9 shopping centres.

8.6 Conclusions

Although the different types of neighbourhoods have different mean pedestrian accident rates, as revealed in Chapter 6, individual neighbourhoods of the same type are not equally safe or unsafe. In fact, accident rates vary considerably within each of the neighbourhood categories. One planned neighbourhood unit even has a higher pedestrian accident rate than the average for the grid neighbourhoods; and six hierarchically organized neighbourhoods have higher rates than the average for the independently designed units. These variations can be attributed to differences in their local environmental configurations. In relation to the research hypotheses that form the basis of this chapter, five main conclusions can be drawn.

First, as expected, those grid neighbourhoods that have the highest accident rates tend to be closely associated with the following environmental features:

(1) strip commercial development along thoroughfares,

(2) linear arrangement of multi-family dwellings on heavily trafficked streets,

(3) poorly insulated arterial roads that intrude into neighbourhoods and separate local service facilities from parts of their service areas.

Commercial ribbons are particularly hazardous for pedestrians, more so than apartment strips since they tend to generate more frequent cross-street pedestrian movement. Since most commercial ribbons and apartment strips are situated on neighbourhood boundaries, they also account in part for the unusually high accident density on the boundary streets of grid neighbourhoods in general. The safety effects of intrusive arterial streets, on the other hand, are more difficult to generalize about because several of them are also commercial ribbons or apartment strips. Nonetheless, the occurrence of these three features is clearly associated with the highest pedestrian accident rates in Edmonton, not just for grid neighbourhoods but for all neighbourhoods. They therefore contribute to the general variation among neighbourhood types, especially in terms of the difference between planned and unplanned neighbourhoods. It is logical to infer, for instance, that the virtual absence of these particularly hazardous features from fully-planned neighbourhoods (types 3, 4 and 5) accounts in some degree for their relatively low mean pedestrian accident rates. The intermediate position of the modified-grid neighbourhoods is also revealing once again. They are the only other neighbourhoods to be associated with these particular features, but only in a limited way, a pattern that mirrors their ranking between the neighbourhoods of type 1 and type 3. It can therefore be concluded that reducing or, better still, preventing the development of commercial ribbons, apartment strips and intrusive arterial streets have been effective means of improving pedestrian safety in Edmonton.

Second, while independent neighbourhood units in general are safer pedestrian environments than either grid or modified-grid neighbourhoods, those that are bounded by arterial streets with peripheral houses facing on them do tend to have the highest accident rates for their type. It seems that where large volumes of traffic move at high speed and frequent cross-street pedestrian movement is necessary, the combination of service roads and controlled crossings is inadequate for pedestrian safety. This feature also lends explanation for the variations in pedestrian accident rates between the independent neighbourhood units and the hierarchically organised neighbourhoods. As will be remembered, in the latter, peripheral houses along arterial streets are normally reversed to face internal streets, and pedestrian access to these streets is strictly limited. Correspondingly, the hierarchically organized neighbourhoods in general have lower pedestrian accident rates. The validity of this explanation can be supported by the research finding that those independent neighbourhood units that are bounded by arterial streets with reversed flanking houses also have relatively low pedestrian accident rates. This also confirms the theoretical expectation, first stated in Section 2.3.1.2, that fully insulated arterial streets with reversed frontages should be the safest form of arterial street design.

Third, the variations in accident rates and the differences in local environmental configuration for the neighbourhoods of hierarchical organization are relatively weakly associated. For example, although elongated communities with relatively long collector streets tend to be associated with neighbourhoods that have above-average pedestrian accident rates for their type, a number of neighbourhoods that also belong to elongated communities have below-average accident rates, and some belonging to compact communities have higher rates. These variations could not be explained by environmental factors and should be attributed to other causes, especially behavioural ones. After all, environmental solutions cannot prevent accidents entirely, even on the internal streets of modified-Radburn and cluster-plan neighbourhoods where the incidence of pedestrian accidents is generally low by Edmonton standards.

Fourth, neighbourhoods, whether planned or unplanned, that are adjacent to heavy external traffic generators (or incompatible land uses) tend to have higher pedestrian accident rates than those that are not, given that they have similar street patterns. Generally speaking, the externalities of incompatible land uses are worse in unplanned than in planned residential areas. In the former, the grid street network has a high potential for through traffic generated by incompatible land uses, which demands massive remedial measures, thus making traffic control difficult. In the latter, the externalities are not as widely spread because of the curbing effects of the hierarchically structured street network. Still, without incompatible land uses, or with proper segregation from their surrounding residences, planned residential areas of all types will be much safer, even with their current combinations of the critical design elements.

Finally, while commercial land use seems to generate more pedestrian accidents than other types of land use in both unplanned and planned residential areas, it was found that shopping centres are a safer form of commercial land use organization than commercial ribbons. This conclusion implies that neighbourhoods adjacent to shopping centres should have lower pedestrian accident rates than those fronting on commercial ribbons.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The thesis research was designed as a systematic evaluation of planned residential environments from the standpoint of pedestrian safety. This is a Canadian case study in a field that has been dominated by European studies. More particularly, the objectives of the thesis were (1) to discover if planned residential environments in general are safer for pedestrians than unplanned environments, and following from that to determine which form of built environment is safest; (2) to assess the relative effectiveness of the alternative forms of the individual design elements that planners have traditionally manipulated in their quest for safer environments; and (3) to determine whether individual neighbourhoods of the same general form vary in their degrees of pedestrian safety, and whether those variations can be attributed to local differences in particular environmental features that are either characteristic of the general form or depart from it in some way.

It must be stressed at the outset that although the thesis research has proved some important relations between the incidence of pedestrian accidents and variations in environmental design, this by no means implies that environmental factors are the sole causes. Human behaviour also contributes to the incidence of pedestrian accidents, which is why education and regulation are necessary accompaniments of environmental solutions. What the thesis research did was to evaluate different forms of built environment, each of which is characterized by distinctive environmental solutions, for their relative effects on pedestrian safety. By evaluating past practice, we can avoid committing old mistakes and build on the success of the past to create safe residential environments, in which pedestrian exposure to traffic hazards is minimized and the points of pedestrian-vehicle conflict reduced. As Roberts (1990:35) has put it, "A good physical environment is one where you will not be threatened by motor vehicles ... and where vehicles do not impair your access to things you need to reach safely, easily and quickly". Such an environment makes no unreasonable demands on human capabilities either, thus encouraging the practice of appropriately learned driving and walking behaviours and making it unnecessary to rely on extensive use of regulatory devices. With this in mind, we now turn to the conclusions of the thesis research.

To begin, pedestrian accidents are indeed a salient problem in residential areas, as the Edmonton case demonstrates. Eighty per cent of Edmonton's pedestrian accidents in the years 1982-1990 occurred in residential districts, including the arterial streets which form neighbourhood boundaries in much of the city. These accidents were widely but unevenly distributed over some 150 neighbourhoods, which was sufficient in itself to suggest that differences in the environmental characteristics of those neighbourhoods might have a significant bearing on their relative safety.

To uncover the associations between pedestrian accidents and the variability that built residential environments display in their physical form, research hypotheses were formulated and tested from three perspectives: (1) the safety effects of general neighbourhood forms based on their classification into 5 type configurations; (2) the effectiveness of planned circulation systems, both vehicular and pedestrian; and (3) the influences of varying local environmental configurations. The hypotheses relating to general neighbourhood form aimed at proving the expected variations in pedestrian accident rates among the different types of neighbourhoods in Edmonton; while the hypotheses relating to planned circulation systems and local environmental configurations were intended to explain the variations in pedestrian safety among neighbourhoods of different types, and also among neighbourhoods of the same type.

With regard to general neighbourhood form, it was found that planned neighbourhoods of all types are indeed safer than unplanned ones for pedestrians of all age groups; in fact, even the partially planned modified-grid neighbourhoods are safer, on average, than Edmonton's grid neighbourhoods. It was also found, turning to the various types of planned neighbourhoods, that those of hierarchical organization are generally safer than the independently designed neighbourhood units. The difference between them, however, shows up only on their boundary streets, not in their interiors, as no significant variations were determined in their mean intra-neighbourhood pedestrian accident rates for any age group. This signifies that inter-neighbourhood organization is an especially important factor in pedestrian safety, and that environmental configurations that are designed to minimize the risk associated with pedestrian trips between neighbourhoods are more effective than the changes that were made to the internal street layouts and block patterns of conventional neighbourhood units. As a corollary to that conclusion, it was found, contrary to original expectations, that hierarchically organized neighbourhoods characterized by superblocks and separate footpath networks (i.e. the modified-Radburn neighbourhoods) are not significantly safer than any other form of planned residential development in Edmonton.

As far as the safety of children and the elderly are concerned, it was found that all types of planned neighbourhoods are equally safe for elderly pedestrians in Edmonton, but the neighbourhoods in hierarchical structures are definitely safer than the independently designed ones for children of 5-14 years. This age group corresponds most closely to the population of elementary and junior-high school students, who are more likely to walk to school than senior-high school students. They benefit particularly from the enhanced safety of inter-neighbourhood travel that hierarchical structures appear to provide.

The relative safety effects of the different types of neighbourhoods can be attributed to a large extent to their distinctive street patterns. For example, grid neighbourhoods have a higher street density, a higher intersection density, and more entrances/exits than any other form of neighbourhood. Besides, grid streets are straight and closely interconnected, which gives them a high potential for through traffic. Most street junctions are cross-intersections as well, by far the most dangerous type of intersection in Edmonton. Given this combination of features, it is scarcely surprising that grid neighbourhoods have the highest mean pedestrian accident rates. In contrast, street density, intersection density and entry points are deliberately reduced in planned neighbourhoods of all types. More importantly, the streets are organized into well-differentiated networks of curvilinear form, including numerous loop streets and culs-de-sac and a predominance of T-intersections. Reducing the number of neighbourhood entrances/exits, particularly in the modified-Radburn and cluster-plan neighbourhoods, seems to have been especially important. It means that there are fewer intersections, fewer crosswalks and fewer conflict points on boundary streets, and that through traffic in neighbourhood interiors is minimized.

Following from this conclusion, although no variation was found among the different forms of planned neighbourhoods with regard to their intra-neighbourhood pedestrian accident rates, superblocks and cluster blocks, which are standard in the modified-Radburn and cluster-plan neighbourhoods, should still be considered as superior to conventional blocks, even in their irregular form. If nothing else, Edmonton's combination of superblocks and cluster blocks contributes to a further reduction of street density, intersection density and the number of neighbourhood entry points, all of which are positively correlated with pedestrian accident rates.

While the expected effectiveness of short-loop streets, culs-de-sac and T-intersections as environmental solutions was largely confirmed, that of separate footpaths was not. This explains why the modified-Radburn neighbourhoods with separate footpath networks do n have lower mean pedestrian accident rates than cluster-plan neighbourhoods, given that their land use patterns, street patterns and block patterns are basically the same. This also suggests that attempting to move pedestrians from sidewalks to separate footpaths is much less effective than controlling and channelling vehicular traffic on internal neighbourhood streets. However, this result should not be interpreted as conclusive evidence that the Radburn concept has no safety advantage over the cluster-plan concept. Rather, it may be a consequence of the modifications that were made to the Radburn model in Edmonton's suburbs. Since traffic on Edmonton's footpath networks is not channelled as closely as the Radburn concept proposed, and all footpaths cross streets (even arterial streets) at grade, pedestrians in neighbourhoods of the modified-Radburn form can more readily choose routes that follow and cross streets in the conventional way.

In addition to the effects of the various street-related features, variations in pedestrian safety among Edmonton's different types of neighbourhoods can be attributed to variations in local environmental configuration, and especially to variations in local land use arrangements. Individual neighbourhoods with the same general street patterns do not have identical accident rates; and the unusually high occurrences of accidents in certain neighbourhoods, which are often related to the spatial pattern of vehicular and pedestrian traffic generators, explain some of the between-category differences in pedestrian safety, especially between unplanned and planned residential environments.

In the unplanned or grid residential areas in Edmonton, the following 4 environmental features are closely associated with those neighbourhoods that have the highest accident rates:

(1) strip commercial development along thoroughfares
(2) linear arrangement of multi-family dwellings on heavily trafficked streets
(3) poorly insulated arterial streets that intrude neighbourhood interiors and separate local service facilities from parts of their service areas

(4) incompatible land uses that attract external traffic. It can certainly be said that were it not for these features, the mean pedestrian accident rate for the grid neighbourhoods would not have been as high as it is. Since these features bear so critically on pedestrian accidents, their general absence (especially the first three) in planned residential areas, and in the modified-grid neighbourhoods for that matter, provides an important explanation for the lower mean pedestrian accident rates there. In other words, planned residential areas are made safer for pedestrians partly because the above features were deliberately prevented from occurring. Above all, commercial and apartment ribbons were replaced by unified shopping centres and carefully designed apartment clusters.

Although incompatible land uses are unusual in planned residential areas, they still constitute an important feature of local environmental configuration in some neighbourhoods with relatively high pedestrian accident rates, most commonly in the form of district or regional shopping centres. These are regarded as incompatible in their host neighbourhoods or communities because they serve larger areas but are poorly segregated from the surrounding neighbourhoods to which they draw large amounts of external traffic. Despite their negative effects, however, they are much safer for pedestrians than unplanned commercial ribbons, and neighbourhoods adjoining them are, in general, safer than those that include strip commercial development.

In addition to incompatible land uses, there are other local features of environmental configuration that relate to a high incidence of pedestrian accidents in planned residential areas. Thus, in the areas consisting of independent neighbourhood units, arterial streets with dwellings facing on them or with major pedestrian trip generators (such as shopping centres and schools) along them, make less safe neighbourhood boundaries, even with service roads, than those with reversed frontages. To turn this around, reversing the frontage of houses abutting on arterial streets does have the merit of reducing the occurrence of pedestrian accidents and is, therefore, is an effective environmental solution. This conclusion also lends further explanation to the differences in pedestrian accident rates between the independently designed neighbourhoods and those of hierarchical organization. In the latter, peripheral houses along arterial streets are normally reversed to face internal residential streets, and major pedestrian trip generators are deliberately prevented from locating on arterials. Partly because of these features, the hierarchically organized neighbourhoods in general have lower pedestrian accident rates and lower proportions of accidents on their boundary streets, than do independent neighbourhood units.

Pedestrian accident rates also vary among the neighbourhoods of hierarchical organization, but to a much lesser extent than among those of other types. Although there is evidence that elongated community shape and incompatible land uses are both associated with a relatively high incidence of pedestrian accidents in this particular type of residential environment, the effects of the former are not as clear cut, since a number of neighbourhoods that also form elongated communities have low accident rates, while a few belonging to compact communities have relatively high rates. This result demonstrates that environmental factors alone cannot explain the incidence of all accidents; when frequencies are low and spatial patterns indeterminate, pedestrian accidents were more likely to have happened randomly, and should be attributed to other factors, especially human behaviour.

In sum, the thesis reveals that the various planning efforts to enhance pedestrian safety through environmental solutions have by and large been successful in Edmonton's residential development. Generally speaking, the modified-Radburn and cluster-plan neighbourhoods that form units in hierarchical structures, provide the safest residential environments for pedestrians. Their safety effects mainly resulted from the adoption of the following environmental solutions:

(1) organizing residential streets into functional hierarchies, together with the maximum practicable use of loop streets, culs-de-sac, and T-intersections;

(2) minimizing street density, intersection density and

especially the number of neighbourhood entry points, along with the employment of superblocks and cluster-blocks as the standard block patterns;

(3) reversing peripheral houses so that they do not front on arterial streets;

(4) arranging local service facilities so as to minimize the number of streets (especially arterial streets) that pedestrian users from their service areas have to cross to reach them, such as combining schools and playgrounds with dwellings in superblocks, and hierarchically organizing those facilities that need the population of more than one neighbourhood to support them in accordance with their intended service areas and with street hierarchies.

Finally, it is worth observing that the findings from the European studies reviewed in Chapter 2 are largely proved by the thesis research in the Canadian context. The main exception is that there is no evidence in the Edmonton case that where separate footpaths are provided, pedestrian accident rates are at the lowest level of all.

9.2 Limitations of the Research

While the stated objectives of the thesis were fulfilled, it is not claimed that the research represents a complete investigation into relations between pedestrian accidents and the residential environment. Three limitations are particularly important. First, no systematic observation was conducted into pedestrian behaviour in relation to different environmental features. For example, it was assumed in the thesis that commercial ribbons and apartment strips are hazardous for pedestrians because they generate more cross-street pedestrian trips than normal streets do. But the actual behaviour of pedestrians on these streets was not investigated, nor was there information on their actual flow patterns. As a result, the considerable variations in pedestrian accident densities among commercial ribbons and among apartment strips (see Tables 8.2 and 8.3) could not be explained. Similarly, it is not clear how pedestrians in general perceived the footpath networks behind houses or through parks in Edmonton's modified-Radburn neighbourhoods, and whether the separate footpaths were being regularly used by pedestrians in the intended manner.

Second, no data could be found to demonstrate whether there are significant differences between suburban neighbourhoods and inner-city neighbourhoods in terms of the proportion of school-age children who are bused to school. As was mentioned in Chapter 8, suburban neighbourhoods in Edmonton were developed in phases and local service facilities were to be provided as the population grew to require them. Some neighbourhoods still do not have a public elementary school of their own, though school sites have been reserved for future development. For the research problem, this means that it is possible that the proportion of children being bused to school is higher in suburban neighbourhoods than in inner-city neighbourhoods, thus contributing to the relatively low pedestrian accident rates of school-age children there. School closures must have altered journey-to-school patterns as well, and so may have affected pedestrian accident rates in some neighbourhoods. More generally, these points underline the problem that the thesis presented of having to interpret pedestrian accident patterns without definite information on numbers and types of pedestrians or their reasons for walking.

Third, because pedestrian accident records from the Edmonton Transportation Department do not report where the victims lived, the thesis research could not distinguish between accidents to residents and non-residents. For instance, there were accident clusters around such incompatible land uses as Northlands Coliseum-Exhibition Grounds, Commonwealth Stadium and West Edmonton Mall (see Figures 8.1 and 8.9), but some of the victims could have been non-local visitors or spectators. This complication has the potential to affect the use of pedestrian accident rates that were calculated using all accidents in each of the study neighbourhoods, where the aim was to compare the relative safety of the five types of neighbourhoods for their residents.

In future research, behavioural studies should be included to gain a closer understanding of how pedestrians behave in different types of built environment, or how they respond to different normative environmental solutions geared towards their safety. Behavioural studies, for example, may provide further explanation for the result that the separate footpaths in the modified-Radburn neighbourhoods in Edmonton do not show any safety advantage, when in theory they should. Studies at a local scale would be useful in disclosing the safety effects of individual environmental features such as commercial ribbons and shopping centres by taking pedestrian behaviour into consideration, thus contributing to a more complete understanding of the overall pedestrian safety of different environmental configurations.

9.3 Recommendations

The conclusions reported in Section 9.1 lead to the following recommendations for future residential planning and design:

1. Area-wide environmental solutions are more effective than localized measures. In order to create residential environments that are safe for pedestrians, residential areas should continue to be planned following neighbourhood unit principles, with curvilinear streets and limited accesses. However, since it is uneconomical to make each neighbourhood unit functionally self-contained, sharing of local service facilities by adjacent neighbourhoods is necessary and inter-neighbourhood pedestrian trips are therefore unavoidable. "If that part of the journey from home to destination that lies outside the immediate neighbourhood cannot be made safely and

easily by bike or on foot, the environmental and safety gains made inside neighbourhood traffic calmed areas are unlikely to be fully utilized" (Tolley, 1989:73). For this reason, individual neighbourhoods should be deliberately configured to form communities following the principle of hierarchical organization. No incompatible land uses that generate heavy external traffic, including regional shopping centres should be incorporated into communities.

2. Having service facilities within walking distance is a key indicator of local quality of life (Hanna, 1990). Since low residential densities lead to wide geographical spread of service facilities and thus dispersed patterns of activities, they encourage unrestrained car use and generate extra vehicular traffic in residential settings. To reduce the physical distances of local service facilities from homes and encourage walking, residential densities should be increased. Moreover, elongated (or oversized) communities should be avoided. The optimum size of a community should be three to four neighbourhoods, with compact shapes, unless local terrain does not permit such an arrangement. Smaller communities generate lower volumes of intra-community traffic on both neighbourhood collector streets and the neighbourhood boundary streets within communities.

3. Shopping centres are to be preferred to commercial ribbons for the spatial organization of retail and commercial service facilities. At the neighbourhood level, these can be

open centres, with various shops grouped around an off-street parking bay. District or regional shopping centres should be well insulated from their adjoining neighbourhoods. Entrances to rear parking lots should not be provided from internal neighbourhood streets which directly serve dwellings. For the convenience and protection of shoppers using public transit, a bus bay should be provided on the mall side of the street for buses travelling in both directions to collect and deliver passengers, so that bus riders do not have to cross the flanking arterial street when coming to and leaving the mall. Strip commercial development can be justified only if it is pedestrianized, where all vehicles are banned except public transit, or if it has shops on one side of the street only with a service road to separate pedestrian shoppers from fast-moving through traffic.

4. Avoid locating schools and shopping centres on opposite sides of the same arterial street, as such a land use arrangement induces students to jaywalk. They can purchase a snack and run back to classrooms within the time of a recess. It is often when they run to the shops or run back to their classroom that the students are at great risk of accidents. Under such circumstances, no form of traffic control device will be really effective.

Also avoid locating senior citizens housing and shopping centres on opposite sides of the same arterial street, since it is too demanding for the elderly to have to cross an arterial street every time they visit a shopping centre.

5. Multi-family dwellings should be clustered around courts adjacent to collector streets. A linear arrangement of apartment buildings and townhouses along arterial streets should be avoided, even with service roads.

6. Streets in residential areas should be laid out with a definite hierarchical order. On the arterial streets forming community boundaries, priority should be assigned to vehicles. In order to channel through traffic efficiently, arterial streets can be laid out in grid forms. To reduce pedestrian-vehicle conflicts, peripheral houses should be reversed with buffers, neighbourhood entrances/exits strictly limited, and all pedestrian trip generators removed from arterial streets.

On collectorized neighbourhood boundary streets and especially neighbourhood collector streets, accommodation of pedestrians must be considered. These streets should curve to reduce vistas and hence discourage speeding. On-street parking should be regulated and front-drive garages removed (unless service roads are provided) because they interrupt desired traffic flows on collector streets and pedestrian movement on sidewalks.

Access streets should be laid out in the forms of short loops and culs-de-sac. Curb parking and front-drive garages are suitable on access streets because speeding is less likely to be a problem there. In cluster-plan neighbourhoods with core superblocks, culs-de-sac should not be dead-end streets for pedestrians. Connecting footpaths ought to be provided as shortcuts to schools and playgrounds, to divert pedestrians from streets and to make their routes as direct as possible.

7. Though cross-intersections have more conflict points than T-intersections, they are more efficient for channelling straight-through traffic, and so are the preferred form of intersection on arterial streets. However, they should be fully controlled with traffic lights to clearly assign right-of-way to pedestrians as well as to vehicles travelling in different directions.

On lower level streets, especially where fast-moving vehicles are unwanted and traffic lights are not warranted, T-intersections are preferred because they have fewer conflict points. Acute-intersections should be avoided; so should traffic circles.

8. In general, superblocks and cluster blocks (laneless subdivisions) are preferred to conventional blocks, because they naturally lead to low street density and low intersection density. They also eliminate the points of conflict between pedestrians and vehicles at the backlane openings associated with conventional blocks. When multi-family dwellings are combined with schools, playgrounds and community league halls on the same superblocks, cross-street pedestrian flows can be considerably reduced. Conventional blocks with backlanes and rear garages can be employed along collector streets, so that normal traffic flows (including buses) on collector streets

will not be interrupted by the vehicles entering or leaving the front-drive garages associated with cluster blocks.

9. If complete segregation of pedestrians from vehicles is not planned with grade-separated crosswalks, it is not worth developing extensive footpath networks. However, discontinuous footpaths should be provided as shortcuts to connect culs-de-sac to sidewalks on collector streets and to playgrounds and schools in superblocks.

If sidewalk networks are provided as the only form of pedestrian facilities, superblocks and cluster blocks should not be too large, so that pedestrians would be forced to follow indirect routes, or go out of their way to reach a traffic-controlled crosswalk. In front of schools and shopping centres along collector streets, mid-block crosswalks should be provided, preferably in the form of a "speed-table". Raised to the level of sidewalks, speed-tables allow easy crossing by pedestrians and increase their visibility.

Shared surface streets (integration) are not recommended, except for short culs-de-sac, where light pedestrian movement does not justify the cost of providing sidewalks.

10. Finally, public policies should be formulated and adopted that appropriately balance the rights of motorists and pedestrians. Such policies are needed to justify some of the environmental solutions recommended here, since certain measures geared to pedestrian comfort and safety often require some sacrifice of motorists' convenience. The recommendation

of designing collector streets in curvilinear forms and providing speed-tables are examples. Without an unambiguous statement of pedestrian rights in the form of a charter or statute, the implementation of environmental solutions may encounter strong opposition from those taxpayers who are fond of driving and have little sympathy for pedestrians.

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Appendix 1
Statistical hypotheses and F-test result using the pedestrian accident rates for children 0-4 years old

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	5.75	2.37	reject H_0

Appendix 2
Statistical hypotheses and t-Test results using the pedestrian accident rates for children 0-4 years old

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.008	53	2.47	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.009	77	2.42	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	54	3.69	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	61	2.45	1.67	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.665	49	-0.43	1.68	do not reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.336	25	0.43	1.71	do not reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.178	32	0.94	1.68	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.174	49	0.94	1.68	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.107	56	1.25	1.68	do not reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.817	38	-0.91	1.71	do not reject H_0

Appendix 3
Statistical hypotheses and F-test result using the pedestrian accident rates for children 5-14 years old

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	37.60	2.37	reject H_0

Appendix 4
Statistical hypotheses and t-Test results using the pedestrian accident rates for children 5-14 years old

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq 0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.000	54	3.76	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq 0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	63	6.87	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq 0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	50	7.30	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq 0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	50	7.30	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq 0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.020	32	2.11	1.69	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq 0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	20	5.12	1.73	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq 0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.000	23	4.70	1.71	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq 0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.005	48	2.60	1.68	reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq 0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.004	55	2.80	1.67	reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq 0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.889	38	-1.30	1.69	do not reject H_0

Appendix 5
Statistical hypotheses and F-test result using the pedestrian accident rates for children 15-19 years old

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	13.90	2.37	reject H_0

Appendix 6
Statistical hypotheses and t-Test results using the pedestrian accident rates for children 15-19 years old

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\le 0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.058	41	1.59	1.68	do not reject H_0
H_0: $\bar{X}_1-\bar{X}_3\le 0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	74	4.06	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\le 0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	49	6.54	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\le 0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	54	4.36	1.67	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\le 0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.039	32	1.79	1.69	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\le 0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	20	4.77	1.72	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\le 0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.009	37	2.58	1.68	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\le 0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.003	48	2.83	1.68	reject H_0
H_0: $\bar{X}_3-\bar{X}_5\le 0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.094	42	1.33	1.68	do not reject H_0
H_0: $\bar{X}_5-\bar{X}_4\le 0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.22	25	0.77	1.71	do not reject H_0

Appendix 7
Statistical hypotheses and F-test result using adult-pedestrian accident rates

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	25.83	2.37	reject H_0

Appendix 8
Statistical hypotheses and t-Test results using adult-pedestrian accident rates

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.002	59	3.03	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	50	5.72	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	44	6.64	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	45	5.39	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.013	26	2.28	1.71	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	20	4.69	1.73	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.000	21	3.87	1.72	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.001	55	3.08	1.67	reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.008	55	2.49	1.67	reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.423	47	0.19	1.68	do not reject H_0

Appendix 9
Statistical hypotheses and F-test result using elderly-pedestrian accident rates

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	19.42	2.37	reject H_0

Appendix 10
Statistical hypotheses and t-test results using elderly-pedestrian accident rates

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.002	55	2.99	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	59	6.09	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	72	5.49	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	56	5.78	1.67	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.009	30	2.45	1.70	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.024	44	2.01	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.000	28	3.59	1.70	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.393	54	0.27	1.67	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.057	54	1.60	1.67	do not reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.809	49	-0.88	1.68	do not reject H_0

Appendix 11
Statistical hypotheses and F-test result using the intra-neighbourhood pedestrian accident rates for children 0-4 years old

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.138	4 148	1.77	2.37	do not reject H_0

Appendix 12
Statistical hypotheses and F-test result using the intra-neighbourhood pedestrian accident rates for children 5-14 years old

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	14.42	2.37	reject H_0

Appendix 13
Statistical hypotheses and t-Test results using the intra-neighbourhood pedestrian accident rates for children 5-14 years old

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.001	52	3.17	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	65	4.08	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	47	5.08	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	54	4.37	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.463	54	0.09	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.016	35	2.21	1.73	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.011	39	2.36	1.73	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.076	51	1.45	1.67	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.006	57	1.58	1.67	do not reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.750	39	-0.68	1.69	do not reject H_0

Appendix 14
Statistical hypotheses and F-test result using the intra-neighbourhood pedestrian accident rates for children 15-19 years old

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{x}_1=\bar{x}_2=\bar{x}_3=\bar{x}_4=\bar{x}_5$ H_1: at least two means are different	0.000	4 148	8.52	2.37	reject H_0

Appendix 15
Statistical hypotheses and t-Test results using the intra-neighbourhood pedestrian accident rates for children 15-19 years old

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{x}_1-\bar{x}_2\leq0$ H_1: $\bar{x}_1-\bar{x}_2>0$	0.021	59	2.09	1.67	reject H_0
H_0: $\bar{x}_1-\bar{x}_3\leq0$ H_1: $\bar{x}_1-\bar{x}_3>0$	0.000	58	3.57	1.67	reject H_0
H_0: $\bar{x}_1-\bar{x}_4\leq0$ H_1: $\bar{x}_1-\bar{x}_4>0$	0.000	49	4.08	1.68	reject H_0
H_0: $\bar{x}_1-\bar{x}_5\leq0$ H_1: $\bar{x}_1-\bar{x}_5>0$	0.004	61	2.69	1.67	reject H_0
H_0: $\bar{x}_2-\bar{x}_3\leq0$ H_1: $\bar{x}_2-\bar{x}_3>0$	0.157	33	1.01	1.69	do not reject H_0
H_0: $\bar{x}_2-\bar{x}_4\leq0$ H_1: $\bar{x}_2-\bar{x}_4>0$	0.018	25	4.77	1.72	reject H_0
H_0: $\bar{x}_2-\bar{x}_5\leq0$ H_1: $\bar{x}_2-\bar{x}_5>0$	0.252	37	0.68	1.68	do not reject H_0
H_0: $\bar{x}_3-\bar{x}_4\leq0$ H_1: $\bar{x}_3-\bar{x}_4>0$	0.139	62	1.08	1.67	do not reject H_0
H_0: $\bar{x}_3-\bar{x}_5\leq0$ H_1: $\bar{x}_3-\bar{x}_5>0$	0.607	44	-0.27	1.68	do not reject H_0
H_0: $\bar{x}_5-\bar{x}_4\leq0$ H_1: $\bar{x}_5-\bar{x}_4>0$	0.095	32	1.32	1.71	do not reject H_0

Appendix 16
Statistical hypotheses and F-test result using the intra-neighbourhood pedestrian accident rates for adults

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	8.39	2.37	reject H_0

Appendix 17
Statistical hypotheses and t-Test results using the intra-neighbourhood pedestrian accident rates for adults

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.019	46	2.12	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	44	3.44	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	43	3.39	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.005	43	2.65	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.055	39	1.62	1.69	do not reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.024	33	2.32	1.72	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.050	31	1.68	1.72	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.290	67	0.55	1.67	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.550	57	-0.13	1.68	do not reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.230	51	0.74	1.68	do not reject H_0

Appendix 18
Statistical hypotheses and F-test result using the intra-neighbourhood pedestrian accident rates for elderly people

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	11.71	2.37	reject H_0

Appendix 19
Statistical hypotheses and t-Test results using the intra-neighbourhood pedestrian accident rates for elderly people

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.009	54	2.40	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	44	4.11	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	41	4.23	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.001	53	3.09	1.67	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.030	26	1.90	1.71	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	18	3.45	1.72	do not reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.111	38	1.23	1.69	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.057	36	1.59	1.69	do not reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.056	32	-0.15	1.69	do not reject H_0
H_0: $\bar{X}_5-\bar{X}_4\leq0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.110	21	1.23	1.72	do not reject H_0

Appendix 20
Statistical hypotheses and F-test result using street density

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	30.66	2.37	reject H_0

Appendix 21
Statistical hypotheses and t-test results using street density

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq 0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.000	38	3.29	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq 0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	77	5.31	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq 0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	73	9.26	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq 0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	50	8.62	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq 0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.155	37	1.03	1.69	do not reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq 0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	35	4.46	1.69	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq 0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.000	37	2.29	1.69	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq 0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.000	68	4.01	1.67	reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq 0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.000	48	4.11	1.68	reject H_0
H_0: $\bar{X}_4-\bar{X}_5\leq 0$ H_1: $\bar{X}_5-\bar{X}_4>0$	0.282	46	0.58	1.68	do not reject H_0

Appendix 22
Statistical hypotheses and F-test result using intersection density

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	50.37	2.37	reject H_0

Appendix 23
Statistical hypotheses and t-test results using Intersection Density

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.000	32	4.72	1.70	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	76	9.35	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	73	11.49	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	56	10.48	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.014	28	2.24	1.70	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	28	4.16	1.70	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.000	30	4.44	1.70	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.004	68	2.69	1.67	reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.000	48	3.36	1.68	reject H_0
H_0: $\bar{X}_4-\bar{X}_5\leq0$ H_1: $\bar{X}_4-\bar{X}_5>0$	0.177	47	0.94	1.68	do not reject H_0

Appendix 24
Statistical hypotheses and F-test result using the number of neighbourhood entrances/exits

Hypotheses	Sig. level	df_1 df_2	Computed F-ratio	Critical F-ratio	Decision
H_0: $\bar{X}_1=\bar{X}_2=\bar{X}_3=\bar{X}_4=\bar{X}_5$ H_1: at least two means are different	0.000	4 148	72.03	2.37	reject H_0

Appendix 25
Statistical hypotheses and t-test results using the number of neighbourhood entrances/exits

Hypotheses	Sig. level	Df.	Computed t-value	Critical t-value	Decision
H_0: $\bar{X}_1-\bar{X}_2\leq0$ H_1: $\bar{X}_1-\bar{X}_2>0$	0.000	44	3.78	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_3\leq0$ H_1: $\bar{X}_1-\bar{X}_3>0$	0.000	66	9.72	1.67	reject H_0
H_0: $\bar{X}_1-\bar{X}_4\leq0$ H_1: $\bar{X}_1-\bar{X}_4>0$	0.000	46	12.38	1.68	reject H_0
H_0: $\bar{X}_1-\bar{X}_5\leq0$ H_1: $\bar{X}_1-\bar{X}_5>0$	0.000	50	10.34	1.68	reject H_0
H_0: $\bar{X}_2-\bar{X}_3\leq0$ H_1: $\bar{X}_2-\bar{X}_3>0$	0.014	28	4.58	1.70	reject H_0
H_0: $\bar{X}_2-\bar{X}_4\leq0$ H_1: $\bar{X}_2-\bar{X}_4>0$	0.000	20	8.50	1.73	reject H_0
H_0: $\bar{X}_2-\bar{X}_5\leq0$ H_1: $\bar{X}_2-\bar{X}_5>0$	0.000	21	7.26	1.72	reject H_0
H_0: $\bar{X}_3-\bar{X}_4\leq0$ H_1: $\bar{X}_3-\bar{X}_4>0$	0.004	48	3.82	1.68	reject H_0
H_0: $\bar{X}_3-\bar{X}_5\leq0$ H_1: $\bar{X}_3-\bar{X}_5>0$	0.000	54	3.53	1.68	reject H_0
H_0: $\bar{X}_4-\bar{X}_5\leq0$ H_1: $\bar{X}_4-\bar{X}_5>0$	0.177	42	0.75	1.68	do not reject H_0