EXPLORING MEASURES OF URBAN FORM:

A GIS-ENABLED CASE STUDY IN HALIFAX, NOVA SCOTIA

by

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Submitted in partial fulfillment

of the requirements of the degree of

Master in Applied Science

Faculty of Graduate Studies and Research

Saint Mary's University

Halifax, Nova Scotia

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Degree: Master of Science in Applied Science

Title of Thesis: Exploring Measures of Urban Form: A GIS-enabled Case Study in Halifax, Nova Scotia.

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APS 603.0 Thesis

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Exploring Measures of Urban Form:

A GIS-enabled Case Study in Halifax, NS

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ABSTRACT

It is critical to understand urban development in order to plan a healthy, affordable, and sustainable future. For researchers, planners and decision-makers, consistent and objective characterization of urban form provides an important means to monitor and evaluate urban development.

This study attempts to characterize urban physical form at the micro level and to reveal historical trends in urban development using measures of urban morphological elements (streets, lots, and buildings). Incorporated with disaggregated data, GIS sampling techniques are able to provide an effective and efficient way to supply data for measure calculations in the study area, Halifax Regional Municipality. Using a variety of statistical methods, the author finds that: 1) Values of descriptive statistics reflect the changes of urban form precisely; 2) In terms of historical trends, land use intensity tends to decline through time; buildings become larger and further apart from each other over time, and they now occupy bigger lots than ever before; and 3) The similarities of urban form across sampling districts suggest impacts of time periods of development, land use, and planning policies.

Overall, this study represents an exploratory exercise to quantitatively delineate urban development, and brings the power, speed, and precision of GIS software and detailed digital data into formal urban analysis regarding development trends.

ACKOWLEDGEMENTS

This thesis would not have been possible without the help of many individuals. I would like to thank Greg Baker for all his help in GIS. Thanks go to HRM planning service - I could not have completed this project without data supplied by them.

A special thanks goes to Dr. Danika van Proosdij for all her GIS related help. Finally, a very special thank you goes to Dr. Hugh Millward for the advice, recommendations, inspiration, and encouragement that helped see this project to completion.

Guang Xue

Halifax, Nova Scotia

July 21, 2005

Table of Contents

CHAPTER - 1 INTRODUCTION 8

CHAPTER - 2 LITERATURE REVIEW 12

CHAPTER - 3 METHODS 31

1. Introduction to the study area, Halifax Regional Municipality 31

2. Data sources 33

3. Sampling Design 35

4. Measure Definitions 41

5. Software applied in this study 44

6. Data collection with ArcGIS 46

7. Measure calculations 49

8. Data processing procedure with SPSS 49

CHAPTER – 4 UNIVARIATE AND BIVARIATE DESCRIPTIVE STATISTICS 51

1. Results of Bivariate correlation analysis 51

2. Descriptive statistics and difference nonparametric test 56

CHAPTER – 5 ALLOMETRIC INTERRELATIONSHIPS BETWEEN MEASURES 74

1. Curve Estimation procedure 74

2. Scatter plot graphs and interpretations 76

CHAPTER – 6 PRINCIPAL COMPONENT ANALYSIS 87

1. Results with 100 meter radius circles 88

2. Results with 200 meter radius circles 92

CHAPTER – 7 CONCLUSIONS 97

REFERENCES 102

APPENDIX-1: THE RESULTS OF MANN-WHITNEY TEST 107

APPENDIX-2: THE VBA SCRIPT FOR ROADCAL 118

List of Tables

Table 2-1 Historical links between transportation technology and urban form 13

Table 2-2 Smart Growth Principles 17

Table 2-3 Several New Urbanism Principles at Neighborhood Level 17

Table 3-1 Paper maps used in the study 34

Table 3-2 Statistical Description of Building Number 40

Table 4-1 Pearson Correlations of Measures (Circles with 100 meters radius) 53

Table 4-2 Pearson correlations of Measures (Circles with 200 meters radius) 54

Table 4-3 Pearson correlations between 2 groups of sampling circles 55

Table 4-4 Descriptive statistics (100m) for different sampling districts 58

Table 4-5 Descriptive statistics (100m) for different land uses 63

Table 4-6 Descriptive statistics (100m) for time period of development 65

Table 4-7 Descriptive statistics (200m) for different sampling districts 68

Table 4-8 Descriptive statistics (200m) for different land uses 69

Table 4-9 Descriptive statistics (200m) for time period of development 71

Table 5-1 R^2 values for Curve Fit (100m Circle) 75

Table 5-2 R^2 values for Curve Fit (200m Circle) 75

Table 5-3 Cases Used (100m) in Analysis after Logarithmical transformation 77

Table 5-4 Cases Used (200m) in Analysis after Logarithmical transformation 77

Table 6-1 Variation Explained (using original data) for components with eigenvalues over 1.0 87

Table 6-2 Variation Explained (using log-transformed data) for components with eigenvalues over 1.0 88

Table 6-3 Rotated Component Matrix* (using 100m log-transformed data) 88

Table 6-4 Variation Explained (using original data) for components with eigenvalues over 1.0 92

Table 6-5 Variation Explained (using log-transformed data) for components with eigenvalues over 1.0 92

Table 6-6 Rotated Component Matrix*(using 200m log-transformed data) 92

List of Figures

Figure 3-1 Urban Growth History of HRM 32

Figure 3-2 Sampling districts in the research 35

Figure 3-3 Sampling circles in the research 37

Figure 3-4 Data collection processing 47

Figure 4-1 Temporal trend of urban development 66

Figure 4-2 Contrasted temporal trend 72

Figure 5-1 Scatter plot graph (100m Circles) 80

Figure 5-2 Scatter plot graph (100m Circles) 81

Figure 5-3 Scatter plot graph (100m Circles) 82

Figure 5-4 Scatter plot graph (100m Circles) 83

Figure 5-5 Scatter plot graph (200m Circles) 84

Figure 5-6 Scatter plot graph (200m Circles) 85

Figure 6-1 Scatter graph for all cases on 2 components (100m circles, log-data) 89

Figure 6-2 Scatter plot for subgroup centroids (100m circles) 90

Figure 6-3 Scatter graph for all cases on 2 components (200m circles) 93

Figure 6-4 Scatter plot for subgroup centroids (200m circles) 94

Chapter - 1 Introduction

The purpose of this research is to develop objective measures of urban form at the micro level which are suitable for GIS (Geographic Information System) applications, and to explore their characteristics, interrelationships, and relationships with different development styles, types of land use, and development time periods in Halifax, Nova Scotia.

A definition of urban form must first be offered. For this study, "urban form" is used to refer to the urban physical realm made up of three physical elements of cities –streets, lots, and buildings and their related spaces. The phrase "micro level" means that all the data for calculating is derived from the individual building, or its adjacent space, or its surrounding streets. Measures which focus on morphological properties of urban form can be divided into four groups: 1) Building density, including gross building density, net building density, gross building coverage ratio, and net building coverage ratio; 2) Building pattern, such as building proximity, mean building size, median building size etc.; 3) Road density, involving gross road density, net road density etc.; and 4) Road design pattern, such as road junction frequency, road connectivity. Details regarding definition and calculation of each measure will be given in chapter 3.

In this study, both archival materials and digital maps will be utilized for data sampling by using the GIS software package, ArcGIS desktop, developed by ESRI (Earth Science Research Institution). The measures are related to many kinds of density and pattern which have been employed in previous studies for mapping and modeling urban development. They will be calculated using data extracted at the site-planning scale. Both univariate and multivariate statistical methods will be used for data analysis.

This study is grounded in the beliefs that: 1) It is critical to understand urban form in order to monitor and control the development and its impacts, since different types of urban form have various and drastic effects on the environment, social issue, and human health; 2) Analysis regarding basic elements of urban form can reveal past trends in urban development, and contribute to predictions and planning about the future development; 3) Empirical measures of urban form can capture well the actual "on the ground" development effects of planning policies, such as transit-oriented development, auto-oriented development etc.; 4) Because of the spatial nature of morphological analysis, GIS packages are appropriate in the research as a speedy and powerful tool.

In the past two decades, more and more people including planners and other decision-makers have realized environmental, economical, social, and human health costs caused by current patterns of urban growth. In response, there have been increased efforts to cope with these problems, through planning approaches such as Smart Growth and New Urbanism. For planners, what they need is applicable measures which can be employed to evaluate the existing of urban form, the adequacy of planning strategies, and their impacts according to the principles derived from these trends. In general, morphological analysis incorporated with disaggregated data could support the implementation of planning goals in three ways: 1) Using detailed data, planners could better match their strategies with particular urban forms in order to re-condense the city; 2) Using detailed information on urban structure, planners could optimize the placement of facilities in order to maximize accessibility and produce mixed-use environments; 3) The use of morphological measures may open up new ways for researchers to measure the effects of different urban forms on transportation, environment, health, behavior, and racial segregation.

The objectives of this research are as follows: 1) To develop efficient sampling techniques in ArcGIS (ESRI) for selection and calculation of key morphological measures; 2) To investigate sampling strategies for consistency and objectivity; 3) To capture and characterize variability of measures and their interrelationships through different urban areas, types of land use, and time periods of development; 4) To recommend key measures for use in urban planning.

The study area of Halifax was founded in 1749. With more than 250 years of development, Halifax has become the major commercial center of Atlantic Canada. Nowadays, there is a metropolitan (CMA) population of 359,000 in this medium-

sized city (Statistics Canada, 2001), which represents 40% of Nova Scotia's population and 15% of all Atlantic Canadians. About 270,000 of these people reside in the urban core (Halifax and Dartmouth), or its suburban areas (Bedford, Sackville, Cole Harbour, and Eastern Passage etc.). Because of its relatively long history of urban development, Halifax is considered as a suitable place for this research. Moreover, another important reason for selecting Halifax is its medium size, in that the data involved will be manageable for a single researcher in terms of data collecting and processing. In addition, data for this study are available and free because of the collaboration between the department of geography and the regional planning unit of Halifax Regional Municipality.

This paper is organized in seven chapters. The next chapter reviews several approaches to measuring urban development in an empirical manner using morphological indices of shape, density, and pattern. In the third chapter, methods regarding sampling and statistical calculations are supplied. In the fourth chapter, outcomes deriving from univariate and bivariate statistics are explored. In the fifth chapter, allometric relationships among measures are explored. Then, the sixth chapter presents the results of multivariate statistics. The final chapter draws the thesis to a close with some conclusions about both theoretical and practical significance of this work in terms of urban development research, policies, and suggestions for further work.

Chapter - 2 Literature Review

Cities have stood out from the countryside as human settlements for a long time. Over time, small and simple settlements have grown into larger and more complex centers for a variety of activities, from agriculture to trade to manufacturing. Though urban growth for every city takes place in a different way, there are certain generalized patterns that are typical in North American cities.

The patterns of development (including aspects such as urban density, land use type and intensity, the existence of centers or corridors, and the appearance of contiguous or "scattered" peripheral areas) in an urban area, collectively called urban form, are shaped by several sets of factors, most notably environmental influences, personal transportation technologies, and planning strategies. Environmental factors such as geology, topography, and groundwater can promote or inhibit development by lowering or adding construction costs and political weight, and thus influence urban form (Millward, in press). According to John Adams (1970) and Truman Hartshorn (1992), personal transportation modes are strongly related to urban structural evolution and have significant influences on urban development. They presented a five-stage model describing the historical links between transportation technology and urban form, shown as Table 2-1. Essentially, planning decisions can produce different impacts on urban form through public capital investments and land use control. Public investment in transportation, public facilities, and infrastructure can shape urban form. For instance, without public water and sewage service, residential development might be restricted to single family houses on fairly large lots; and commercial development could be limited. Land use control, such as subdivision regulations and zoning by-laws, can permit or prohibit the desired or undesired development (Levy, 2000).

Table 2-1 Historical links between transportation technology and urban form

Transportation Technology	Time Periods	Key Characterizations of Urban form
Walking/Horse-car	Prior to 1890	small, compact, very dense
Electric Streetcar	1890 - 1925	star-shaped, dense centre
Motorbus & Early Automobile	1925 - 1955	star-shaped with light exurban scatter
Early Freeway	1955 - 1980	extensive low density suburban
Beltways & Suburban Downtowns	1980 - Present	continuous exurban halo

Source: Millward (in press)

In turn, different types of urban form have various impacts on the environment, social issues, and human health. These impacts are strongly related to land cover, built form, and land use, which are three main components of urban form. For example, development converts land cover from "rough" vegetative surfaces to smooth impervious artificial surfaces, so that storm water retention can be greatly decreased, and peak storm water flows will be well beyond the capacity of the natural drainage systems. Alexander et al. (1977) listed more than 250 urban design patterns which could benefit or harm the nature environment. In addition, the size, shape, and massing of buildings have environmental consequences at a local scale. For instance, a group of buildings could create severe wind-funnel effects especially in the downtown area (Millward, in press). Moreover, land use type and intensity affect the natural environment through the generation of vehicular traffic. Currently, the separation of commercial areas, residential areas, and employment areas has increased both the number and length of vehicular trips. This kind of urban development (sprawl) causes atmospheric pollutants, greenhouse gases, noise, and congestion (Burchell et al., 2002). All these trends aggravate the degradation of environmental conditions, and also contribute to heath and social problems such as obesity, social isolation, public safety, and restriction on the mobility of children and elders (Handy et al., 2002; Ewing et al., 2003a).

Historically, the spaces in most cities where people lived, work, and went to school were closely packed together and intermixed in close proximity to each other. With the advent of railways, street trolleys, and automobiles, cities have increased their spatial extent greatly. As a result, since the 1950's, North American cities have become less dense and dramatically less diverse in their development patterns (Heim, 2001). Metropolitan areas have been expanding outwards far more rapidly than population growth, and have been consuming far more precious natural land than ever before (Johnson, 2001). From the residential development point of view, Jackson (1985) defined the U.S. urban development patterns as "crabgrass frontier", which suggested low residential density and a lengthy journey to work in terms of distance and time.

In a large body of literature, the dominant mode of recent suburban development in North American cities is classified as urban sprawl. In physical terms, "sprawl is automobile-dependent development characterized by low net densities and extremely low gross densities, which proceeds piecemeal and in leapfrog fashion, without overall co-ordination (Millward, in press)." Such development increases costs excessively on urban infrastructure and services, including roads, water lines, sewers, sewage plants, and schools etc.(Burchell et al., 2002; Speir and Stephenson, 2002; Carruthers and Ulfarsson, 2003). Sprawl also has negative effects on the environment, which are well documented for environmental costs, such as unnecessary loss of prime farmlands, picturesque areas, and wildlife habitats (Johnson, 2001; Hasse and Lathrop, 2003; Frumkin et al., 2004). Furthermore, since it is characterized by piecemeal development, sprawl areas also fragment the remaining farmlands, green spaces, and habitats, and result in the degradation of their functionality. In addition, the study conducted by Ewing et al. (2003) showed that sprawl has significant impacts on transportation, in that a highly scattered pattern of land uses and activities is associated with long trips to work, shop, school and play. They found that in general, "people living in more sprawling regions tend to drive greater distances, own more cars, breathe more polluted air, face a greater risk of traffic fatalities, and walk and use transit less."

While sprawl is widely criticized, it is worth noting that there still are individuals who defend urban sprawl. That is, sprawl occurs for reasons. Indeed, sprawl does bring specific benefits for certain individuals. Gordon and Richardson (1997) strongly supported the free-market merits of continued suburbanization. They argued that the decentralized suburban pattern of development offered many advantages, including lower housing costs, higher consumer satisfaction, as well as lower costs for commercial and industrial land uses. In addition, Burton (2000) suggested that, for medium-sized English cities, higher urban densities have reduced living space and affordable housing, and produced a large proportion of high-density and high-priced housing.

Although several researchers have attempted to explore the sprawl phenomenon, including its causes, characteristics, types, costs, and potential controls, the determinants and characteristics of sprawl have not been fully understood. For example, Galster et al. (2001) developed a complex and multi-faceted index to characterize sprawl in eight dimensions: density, continuity, concentration, clustering, centrality, nuclearity, mixed use, and proximity. They defined sprawl as a pattern of land use that has low levels in one or more of these dimensions. In their study for measuring sprawl, Ewing et al. (2003) used twenty-two variables initially, and then combined them into four sprawl factors using principal component analysis. These four factors measure sprawl in four dimensions: Residential density; Neighborhood mix of homes, jobs, and services; Strength of activity centers and downtowns; and Accessibility of the street network. Since most researchers who conducted similar studies have tended to use aggregated data sources and methods which could produce different sets of statistics, they lead to different and even contradictory outcomes and interpretations. Furthermore, most of these examinations used crude measures based on very large units of analysis and are thus probably too coarse to guide planning or policy decision-making at the municipal level (Knaap, 2001).

No matter what kind of form it is in, all development including sprawl can benefit from careful planning (Millward, in press). In recent years, there have been many approaches used to control urban sprawl or mitigate its negative impacts at different scales. At the macro and meso level (regional or metropolitan), "Urban Ecological Planning" aims to optimize the location and pattern of development (McHarg, 1992; Baldwin, 1985; Hough, 1995; Marsh, 1998; Daniels and Daniels, 2003); while "Smart Growth" emphasizes reduction of the urban footprint through "Growth Management" (Duncan and Nelson, 1995; Daniels, 1999; Heim, 2001; Carruthers, 2002), densification, and transit-oriented development. In contrast, at the micro level (community or site), "New Urbanism" advocates a return to traditional (pre-1950) neighborhood development patterns as a means of counteracting suburban sprawl. Table 2-2 and Table 2-3 show the main principles of smart growth and new urbanism.

Note in Table 2-3 and 2-3 that these two planning approaches are strongly interrelated, but New Urbanism is more design-oriented, while Smart Growth is related more to land use and strategic planning. More specifically, New Urbanism deals with a part of the city, while Smart Growth considers the entire city. Both approaches share several concerns in common, particularly the promotion of compactness of urban form, mixture of land uses, neighborhood accessibility, multiple transportation choices, and human physical activity. It is evident that many of these concerns require new measurement methods (Talen, 2002). In practice, without particular tools to effectively measure and represent these ideas implementation, these concepts will be intangible and meaningless.

Table 2-2 Smart Growth Principles

• Mix land uses
• Take advantage of compact building design
• Create a range of housing opportunities and choices
• Create walkable neighborhoods
• Foster distinctive, attractive communities with a strong sense of place
• Preserve open space, farmland, natural beauty, and critical environmental areas
• Strengthen and direct development towards existing communities
• Provide a variety of transportation choices
• Make development decisions predictable, fair, and cost effective
• Encourage community and stakeholder collaboration in development decisions.
Source: Smart Growth Network (2003)

Table 2-3 Several New Urbanism Principles at Neighborhood Level

• Neighborhoods should be "compact, pedestrian friendly, and mixed-use."
• Walking distance and interconnected networks of streets
• Neighborhoods should contain a "broad range of housing types and price levels."
• Properly placed transit corridors can help organize metropolitan structure.
• Appropriate land uses and building densities "should be within walking distance of transit stops."
• A gathering of "civic, institutional, and commercial activity should be embedded in neighborhoods [and] schools should be sized and located to enable children to walk or bicycle to them."
• Urban graphic design codes serve as predictable guides for change.
• "A range of parks ... should be distributed within neighborhoods."
• Using the modified street grid patterns such as diagonals, curves, circles etc.
Source: Leccesse and McCormick (2000)

Incorporated with the principles of Smart Growth or New Urbanism, many studies contribute to methods for measuring concepts such as compactness, access, diversity etc. For example, Burton (2002) developed a large set of indicators based on population density, built form density, and mix of uses, and used them to measure urban compactness in an investigation of sustainability; In 2003, Burton et al developed another instrument to measure the built environment, which could be used to investigate mental heath, physical heath, and social interaction. Bagley et al. (2002) presented a method to assess neighborhood types using several subjective and objective variables derived from New Urbanism principles.

Several researchers have attempted to measure neighborhood accessibility for enhancing transportation choices. In their study, Handy and Kelly (2000) identified two sets of factors that contributed to accessibility at the neighborhood level, and explored different ways for planners to evaluate neighborhood accessibility using existing data sources and GIS. The authors reported that when applied to several kinds of neighborhoods, these measures were used for comparison between study areas to find potential deficiencies and inequities in urban form.

Krizek (2003) calculated three continuous measures housing density, number of employees in neighborhood retail services (representing land use mix), and block size defined by the street network (representing street patterns) - for each 150-meter grid cell within the study area. Then, the author used one principal component and its score as the index to evaluate neighborhood accessibility. The author argued that this method provided continuous and precise measures of urban form at a pedestrian-scale resolution across the entire metropolitan area, rather than relying on relatively atheoretical thresholds to determine the classification of neighborhood accessibility. Conversely, Weber and Kwan (2003) questioned the assumed simple relationship between urban form (mainly relating to distance) and individual accessibility. In their research, space-time accessibility measures were applied to individuals. Based on their findings, they claimed that accessibility could not be determined from location within cities, or from land uses around an individual's home, suggesting that the utility of urban design to influence accessibility might be quite low.

Generally, urban form can be categorized into three fundamental physical elements in terms of urban morphology: buildings and their related open space, land parcels, and streets (Conzen, 1960). For morphological studies, one cannot adequately analyze urban form without considering principles of scale and time (Moudon, 1997). The data should be analyzed at certain scales, which include four different levels ranging from individual buildings, through blocks of buildings, the city, and up to the regional level. Morphological studies also emphasize the historical context since the physical elements of urban form undergo continuous transformation and replacement over time.

According to research conducted by Talen (2002), when combined with a great number of detailed and disaggregated data in a large study area, morphological methods are able to represent the explicit conditions and patterns of urban physical form, and likely to be one of most useful approaches for research regarding the developmental aspects of Smart Growth and New Urbanism. For instance, in a study about the pedestrian environment (1000 Friends of Oregon, 1999), every street segment in the city was evaluated according to four criteria - ease of street crossing, sidewalk continuity, connectivity of street system, and topography. In another study of how the built environment impacts travel demand, Cervero and Kockelman (1997) considered a large number of neighborhood variables including proportion of blocks with sidewalk, block length, number of intersections, and retail store availability to characterize walkable and auto-dependent urban form. Moreover, detailed morphological analysis of urban form has become an important part of decision support tools in planning. In fact, there are several morphological indicators which are widely used in planning software such as INDEX and CommunityViz.

The literature shows that planners and researchers have frequently used density and pattern to quantify urban form. Without exception, urban morphology studies focus on density and pattern of physical elements (streets, lots, and buildings). In general, "Density is the amount of some factors divided by the area that the factors occupy (Ratcliffe, 1981, p397)." The resultant figure expresses the average land use intensity in that area. However, there are no agreed-upon standard definitions of density. Instead, different locations and professions have developed different views. A main area of difference and confusion is how to define the base area - what should or should not be included – in order to make density figures objective and comparable. Thus, there are a number of potential measures of density, and even more of perceived density (Katherine and Forsyth, 2003). In addition, "Pattern is a form, template, or model (or, more abstractly, a set of rules) which can be used to make or to generate things or parts of a thing. Usually, if things have enough in common, it is possible to infer or discern the pattern (Wikipedia, 2005)".

A number of urban morphologists have contributed to analysis of urban form using these elements. In his study about the convergence and divergence of urban forms, Millward (1975) examined all three elements of urban plan to assess similarity or dissimilarity in urban form between national sets of cities, and provided an explanation for increasing similarities in urban form through time. Using 500m x 500m quadrats as a minimum sampling unit, the author developed several measures related to streets and dwelling units obtained from a series of topographic maps. Outlined below are his indicators related to streets:

1) Gross road density: computed as the street length in relation to the total unit area, expressed in kilometres per square kilometre.

2) Net road density: computed as the road length in relation to the amount of the unit actually built-up, expressed in kilometres per square kilometre. It is more useful, since "it represents a virtually completed stage with little possibility of changes due to further development" (p 37).

3) Road junction frequency: equals the total number of junctions (including any convergence or crossing of routes, dead-ends, and abrupt changes of direction along road sections) divided by total road length, and is expressed in junctions per kilometre of road. This measure "not only supplies further evidence of layout density, but also some information regarding cost efficiency and safety" (p 37).

4) Road connectivity: equals the average number of road sections meeting at the junctions. At a four-way intersection, the number is four, at a three-way intersection three, at the termination of a cul-de-sac one, and at a sharp change in direction along the road two. "For traffic flow safety, the fewer road sections per junction the better" (p 39).

5) Angular deviation at junctions: equals the proportion of all intersection angles that deviate by more than ten degrees from a planning norm of ninety degrees, expressed as a percentage. It is known that, "for safety reasons, junctions should be approximately at right angles. Moreover, 90 degrees intersections cut down distorted lot shapes and improve cost effectiveness" (p 39).

6) Road curvature: for parcels containing a road section, the percentage in which a curve or inflexion is present. This measure delineates an important feature of curvilinear layouts "which is preferred by site designers for considerations of safety and speed reduction, and by residents and users for aesthetic reason" (p 40).

The first three indicators measure density and the second three measure pattern. For plots and buildings, attention was focused primarily on different types of density through time, and their relationship with street plan (Millward, 1975). By utilizing these indicators, the degree of similarity in design and scale of plan features was described and analyzed. Millward reported that cities had become increasingly similar in their urban physical form (displaying "morphological homogenization (p163)") because of the adoption of shared innovations such as transportation techniques, planning concepts etc. This research is one of few contributions on the analysis of urban morphological organization, and provided rigorous approaches for measuring urban form.

Other urban morphologists have focused on different aspects and measurements of urban form. Scheer (2000) provided a framework to utilize the spatial ordering components - site, paths, plots, buildings, and objects (including cultivated vegetation, man-made objects, underground infrastructure, and parking lots, driveways, sidewalk, and street paving), which have different rates of change - in order to understand the complex relationships between disparate urban forms. Using squares measuring 1/2 mile x 1/2mile of the township survey system as a base layer, and other layers related to the above components over time, Scheer traced the history of form transformation in the town of Hudson, Ohio and introduced its various formal layers and their relationships as well. The author demonstrated how suburban form was strongly constrained and shaped by the site of the city, the pre-urban cadastre, and pre-urban paths.

The non-stop innovation of GIS techniques, "allied to the proliferation of new, detailed and disaggregated data sources, has been recently ushering in a new era of data-led generalization about the empirical characteristics of urban form at a variety of scales using a variety of geographic units (Longley and Mesev, 2002, p3)". In fact, several researchers have applied these measures to urban development studies at a micro scale. These measures are mainly based on morphological features of urban form, but they take on new meanings as performance measures related to the principles of Smart Growth or New Urbanism.

From the literature, Weston (2002) derived several measures which were designed to evaluate urban form using the main principles of New Urbanism as follows:

1) Dissimilarity index of land use - The study area was first divided into 50 m by 50 m grid squares. A value for one grid cell was based on the land uses of the eight surrounding cells. If each of the eight surrounding cells was a different land use from the cell in question, a value of eight was assigned to it. Then, the index value for the study area equaled the total of all the grid values. The higher the value of the dissimilarity index, the more diverse the area under consideration.

2) Dispersion index of land uses - This measure was introduced from edge analysisin landscape ecology. The index ranged in value from one to zero. A value of one indicates that one type of land use was gathered in a single cluster, while zero indicates that land use types were completely dispersed.

3) Lineal feet of streets (with and without alleys), representing how much of the area was devoted to public access.

4) Ratio between the numbers of street segments and intersections (with and without alleys): a higher ratio indicates more choices for traveling through an area.

5) Number of cul-de-sacs: a high number of cul-de-sacs suggest lengthier routes to avoid dead ends.

6) Number of access points to the sample area, indicating how well the sample area is integrated into the surrounding fabric of the city.

7) Dispersion index based on only two residential land uses - Single Family and Multiple Family.

8) Ratio of multi-family housing to total residential area.

9) Percentage of open space and undeveloped area in the study area.

These measures were applied to seven 1000 m by 1000 m neighborhoods, including two ideal neighborhoods as the "controls" and five neighborhoods developed after World War II as the "comparisons". Comparing with the "controls", the author found that in the "comparison" areas: 1) there were lower scores in the dispersion of land uses; 2) all four measures for the street network suggested that the "comparison" areas had low connectivity and accessibility; 3) there was much less land devoted to multi-family housing; 4) multi-family units were less dispersed. The author claimed that this method could help planners retrofitting existing neighborhoods to more closely adhere to New Urbanism ideals.

In order to better capture actual development patterns, Moudon et al. (2001) developed a method to quantify land use spatial and functional complementarity and the grain of land use mixing. First, tax lots were used as the elementary spatial unit of data collection, and were aggregated into larger patches using GIS according to their land uses and proximities, such as medium-density residential use (25 dwelling units/ha), retail-service use, and school site etc.; Second, data layers were imported into Fragstats (a GIS-based program for quantitative landscape analysis) for supplying several morphological indicators (metrics of Fragstats) such as mean patch size, patch density, interspersion, and juxtaposition etc., which can be interpreted quantitatively in terms of land composition and configuration. The authors claim that this method could overcome limitations on traditional measures of density and land use mix, which result from large and unsuitable geographic units.

Song and Knaap (2004) reported that most previous work on examining urban sprawl, such as Galster et al. (2001) and Ewing et al. (2003), used measures either not related to public policy or based on large units of analysis. Thus, these measures might be too coarse to guide planning or policy making. They presented several revised measures of urban form at the neighborhood level for their detailed analysis, where neighborhood is defined by Traffic Analysis Zones (TAZs are geographic units designed for use in transportation planning and are roughly coincident with census block groups). They divided their measures into 5 groups as follows:

1) Measures for Street Design and Circulation Systems: In their study, street connectivity was regarded as a desired feature in residential areas, in that better connectivity "leads to more walking and biking, fewer vehicle miles traveled, higher air quality, and greater sense of community among residents (p 187)."

Int_Connectivity – number of street intersections divided by the number of intersections plus the number of cul-de-sacs; the higher the ratio, the greater the internal connectivity.

Blocks_Peri – median perimeter of street blocks; the smaller the perimeter, the greater the internal connectivity.

Blocks – number of blocks (Created by winding streets and cul-de-sacs) divided by number of housing units; the fewer the blocks the greater the internal connectivity.

Length_Cul-De-Sac – median length of cul-de-sacs; the shorter the cul-de-sacs, the greater the internal connectivity.

Ext_Connectivity – median distance between Ingress/Egress (access) points in feet; the greater the distance, the poorer the external connectivity.

2) Measures for Density: They insisted "low-density development increases automobile dependence, consumes farmland, and raises the cost of public infrastructure (p 187)".

Lot_Size – median lot size of single-family dwelling units in the neighborhood; the smaller the lot size, the higher the density.

Floor_Space – median floor space of single-family dwelling units in the neighborhood; the smaller the floor space, the higher the density.

SFR_Density –number of single-family dwelling units divided by the residential area of the neighborhood; the higher the ratio, the higher the density. This is a measure of neighborhood density.

3) Measures for Land-use mix: They claim that "greater mixing of uses facilitates walking and biking, lowers vehicle miles traveled, improves air quality, and enhances urban aesthetics (American Planning Association 1998)".

Mix – acres of commercial, industrial and public land uses in the neighborhood divided by number of housing units; the greater the ratio, the greater the mix.

LU_Mix – A diversity index $H_1 = -\Sigma [(P_i) * \ln(P_i)] / \ln(S)$ where H_1 = diversity including SFR, Pi = proportions of each of the five land use types SFR, MFR, Industrial, Public, and Commercial uses, and S = the number of land uses. The higher the value, the less the land use mixes.

NR_Mix –A diversity index $H_2 = -\Sigma [(P_i) * \ln(Pi)] / \ln(S)$ where H_2 = diversity excluding SFR, P_i = proportions of each of the four land use types MFR, Industrial, Public and Commercial uses, and S = the number of land uses. The higher the value, the less the land use mixes.

4) Measures for Accessibility: They reported that it is important to characterize accessibility, since too much separation between different types of land use makes travel distances unnecessarily long.

Comdis – median distance to the nearest commercial use; the greater the distance, the lower the accessibility.

Busdis – median distance to the nearest bus stop; the greater the distance, the lower the accessibility.

Parkdis – median distance to the nearest park; the greater the distance, the lower the accessibility.

5) Measures for Pedestrian Access: Pedestrian access encourages residents to walk, lowers vehicle miles traveled, and improves human health (Frank and Englke 2001). The authors thought that it was necessary to measure this feature.

Ped_Com – percentage of SFR units within one quarter mile of commercial uses; the greater the percentage, the greater the pedestrian accessibility.

Ped_Bus – percentage of SFR units within one quarter mile of bus stops; the greater the percentage, the greater the pedestrian accessibility.

Using these measures, the authors evaluated development trends of residential neighborhoods in three cities in the U.S. and illustrated how urban development patterns differ within and across study areas, and how development patterns have changed over time. They found that there was a similar trend in urban form in these three cities since the 1940s: "1) Neighborhoods in general are all becoming better internally connected; 2) Neighborhoods have increased in single family dwelling unit density, and single family homes have been developed in smaller lots and larger homes; 3) External connectivity is decreasing or not improving; 4) Land uses within the neighborhoods remain homogenous; 5) Accessibility to commercial uses remains poor in the study areas. (p223)" They also argue that these neighborhood-level measures provide not only richer information on the design character of U.S. cities, but also offer new insights into how character has changed over time. Yet, in their study what constitutes a neighborhood remains problematical because TAZs are still too large for detailed analysis and vary in size over the study areas.

In another paper, Song and Knaap (2005) were able to identify all the single family homes constructed in Orange County, Florida in 2000. They computed several measures of urban form for the neighborhood surrounding each building (defined as a half-mile buffer around the building site in this case). Most of their measures used here were similar to those used in their previous 2004 study. Using cluster analysis, the authors identified 5 specific neighborhood types and enumerated how many single family homes were built in each type of neighborhood. This allowed the authors to examine the different kinds of neighborhoods in Orange County in which single family homes were being built. Finally, they used the median dates at which each neighborhood in Orange County was built, and examined trends in urban development patterns over time. They reported changes in the neighborhoods over time as follows: "1) the proportion of cul-de-sacs fell from the 1940s to the 1970s, and began rising in about 1980; 2) the distance between access points into neighborhoods, Single-family house sizes, and the median distance to a commercial use rose throughout most of the post-war period; 3) single-family lot sizes rose through the early post-war period but began falling in about 1970; 5) Land use mix in single family neighborhoods has fallen recently; 6) the percent of homes within ¼ mile of a commercial use has fallen steadily (p16)". The authors claimed that all the trends suggested development trends were lack of the direction of smarter growth.

This literature review shows that: 1) only a modest amount of empirical research has been done for investigating urban form using micro-level measures and disaggregated data in North America, and very little in Canadian cities; 2) little research has compared measures of urban form, and evaluated changes in urban form over time within or across several large study areas; 3) little discussion has been found to evaluate the relationships among measures of urban form and current planning trends. Thus, this study will make several contributions to empirical measurement of urban form. While the focus will be on a single medium-sized metropolis (Halifax Regional Municipality), the results are likely to be broadly indicative of spatial patterning and temporal trends. They will also fill a gap in our knowledge of urban allometry, by looking at interrelationships within the system of morphological elements.

Chapter - 3 Methods

As described in chapter 1, Halifax was considered as a good case study area, mainly because it exhibits various development styles resulting from its relatively long settlement history in the urbanized areas.

1. Introduction to the study area, Halifax Regional Municipality

In 1749, Halifax was founded as a British settlement because of conflicts with the French for control of the region. The site benefited from its natural harbour, and a large hill to aid the defence of the township. Dartmouth was founded the following year across the harbor.

In the early 19th century, Halifax remained an important military base, and had become an important point in trading between Europe and North America. In the 1870's, the population was over 30,000 and a number of industries had been established with more activity in the later years of Confederation (Stephenson, 1957). Before 1900, most development had taken place in the northern area of Halifax peninsula and parts of Dartmouth near the harbor (Millward, 1981).

By 1911, the population increased to 46,619 in Halifax. The expansion of the built-up area was rapid once the electric streetcars or "trolleys" replaced the horse as a means of transit from 1896 and improved commuting speeds (Millward, 1981). During the First World War, Halifax became the major troop port for the country, and much house building occurred around the whole area. Another significant event for the city was the Halifax Explosion on December 6th of 1917, the most powerful man-made explosion before Hiroshima. Most of the North End was flattened, leaving many people homeless in that harsh winter. In the aftermath, "Hydro-stone" buildings were built to house some of the surviving families, but many factories destroyed in the explosion were never reopened. In addition, most businesses in the area suffered before the depression hit.

In 1939, when Canada entered the Second World War, Halifax became an extremely important city as a key convoy port and a major centre for ship-repair. In addition to an economic boom, the city experienced pressures for accommodation and housing owing to a huge influx of military people, service workers, and their families. Many prefabricated houses were built in the northern part of the city at that time. By the end of the war, more than 120,000 people lived in metropolitan Halifax and Dartmouth. The city occupied most of the peninsular, and suburbs stretched along Bedford basin, the North West Arm and harbor-side areas of Dartmouth.

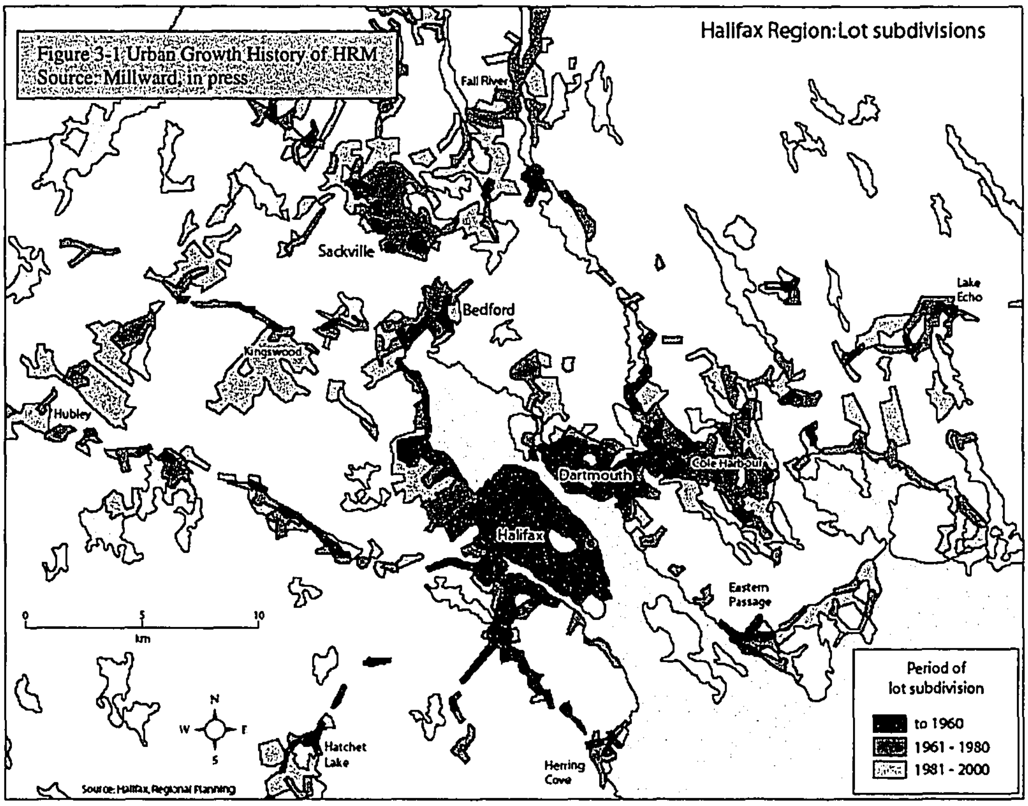


Figure 3-1 Urban Growth History of HRM
Source: Millward, in press

Halifax has increasingly become the regional hub for health care, post-secondary education and various forms of research since the 1950s. The military and especially navy presence in the city has also remained important, but manufacturing continues to struggle. Owing to the opening of the MacDonald Bridge in 1955, there was considerable housing development on the east side of the Harbour, in Dartmouth and Cole Harbour (Millward, 1981). Coblentz (1963) proposed several suitable areas for development, including Sackville, Cole Harbour, and Eastern Passage because of presence of glacial till, which lowers construction costs. Since then, urban expansion has mainly occurred in these areas. The 1975 Halifax regional plan also "recommended major residential expansion in Bedford-Sackville and in Cole Harbor, and minimal development to the west or south of Halifax (Millward, 2005)." Fig. 3-1 illustrates the growth of lot subdivision, which reflects the later expansion of built-up areas from the 1960s to 2000s, since actual constructions usually occur after lot subdividing.

In 1996, the cities of Halifax and Dartmouth, the town of Bedford, and the outlying areas of Halifax County were amalgamated into the Halifax Regional Municipality (HRM). The study areas were selected in a range about 25 km east west and 20 km north south in the downtown, suburban and exurban areas of HRM (see Figure 3-2). The individual sampling districts were selected throughout the urbanized and semi-urbanized areas of HRM.

2. Data sources

In this study, different data sources were chosen for their availability and capability of delivering complete and accurate data within sampling areas. Initially, high-resolution satellite imagery (pixel size less than 5 m by 5 m) was considered for this research.

But high costs on purchasing images made it unfeasible. Thus, primary sources in this study included digital maps and archival maps, as well as topographic maps.

Table 3-1 Paper maps used in the study

Name of MapSheet	Sheet No.	Scale	Surveyed Date
Halifax		1:26,080	1894
Chezzetkcook	11D/11	1:63360	1917
Halifax	11D/12	1:63360	1921
Uniacke	11D/13	1:63360	1920
Chezzetkcook	11D/11	1:50,000	1949
Halifax	11D/12	1:50,000	1950
Uniacke	11D/13	1:50,000	1947
Chezzetkcook	11D/11	1:50,000	1970
Halifax	11D/12	1:50,000	1968
Uniacke	11D/13	1:50,000	1972
SackvilleMap		1:8,000	1975

Many efforts were made to acquire both archival and digital maps whose surveyed dates correspond to the 5 selected time periods of 1890, 1925, 1955, 1980, and the present (based on Hartshorn's urban evolution model), from the possible resources in Halifax such as Public Archives of Nova Scotia, and Map libraries at both Saint Mary's University and Dalhousie University. However, only partial archival map coverage was found. Table 3-1 shows the list of paper maps used, which were scanned at the proper resolution and then geo-referenced spatially. In addition, some of the digital maps used were surveyed only around 1985 because of data availability. The digital map sources are as follows:

1) 1:1000 and 1:2000 digital property maps mapped by LRIS (Land Registration Information System) provided detailed information regarding Buildings and Property Boundaries (lots). The lot data provide most recent information for 2005. However, the building footprints are based on air photographs for the mid-1980s. More recent mapping is available, but only through subscription which is too costly.

2) The road and land use datasets were derived from CanMap®5.0 (mapped on 1:50,000 National Topographic Series) by DMTI spatial. The DMTI maps were based on the data surveyed approximately in 1997.

3) Halifax Regional Municipality zoning map created by Halifax Planning Service was used to obtain land use information. These data are current for 2005.

Overall, the whole study is constrained by the date of the earliest data which is for building footprints.

3. Sampling Design

Sampling Districts

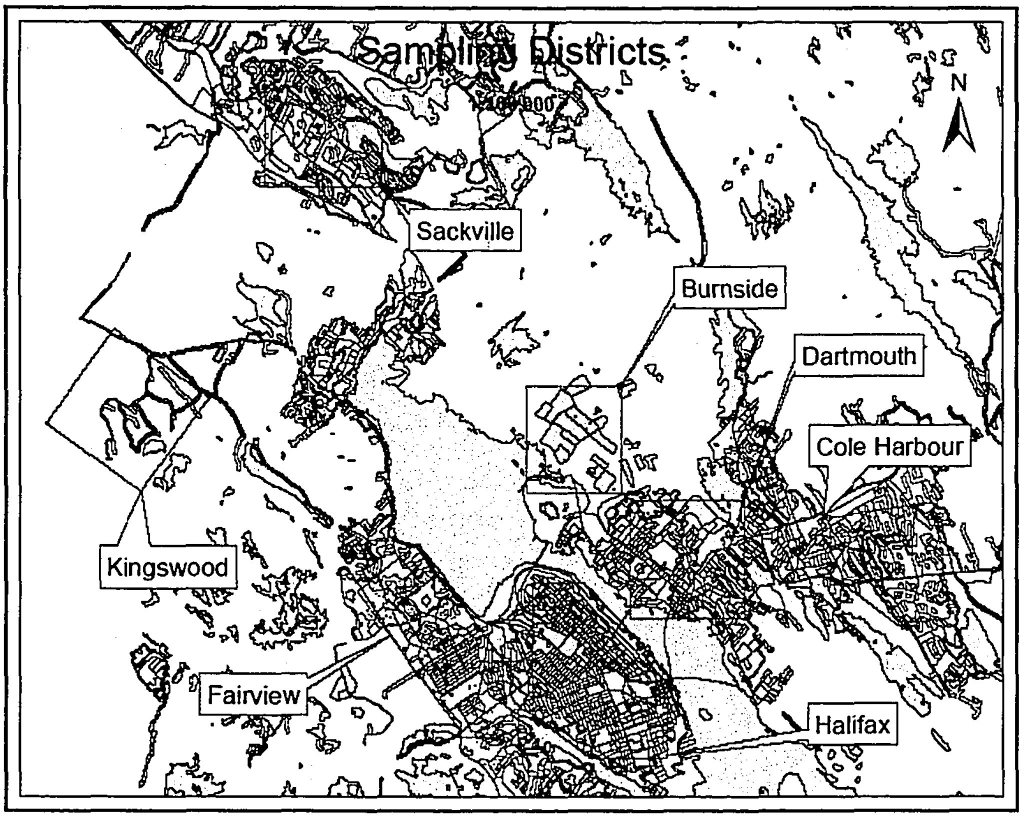


Figure 3-2 Sampling districts in the research

In this research, a nested sampling procedure was applied. Seven districts of sampling points (Totally 219 points) were located in different parts of the study area (shown as Fig.3-2). Within these districts, a point sampling procedure was used to select the central locations for sampling circles to ensure various styles of land use as well as different periods of urban development.

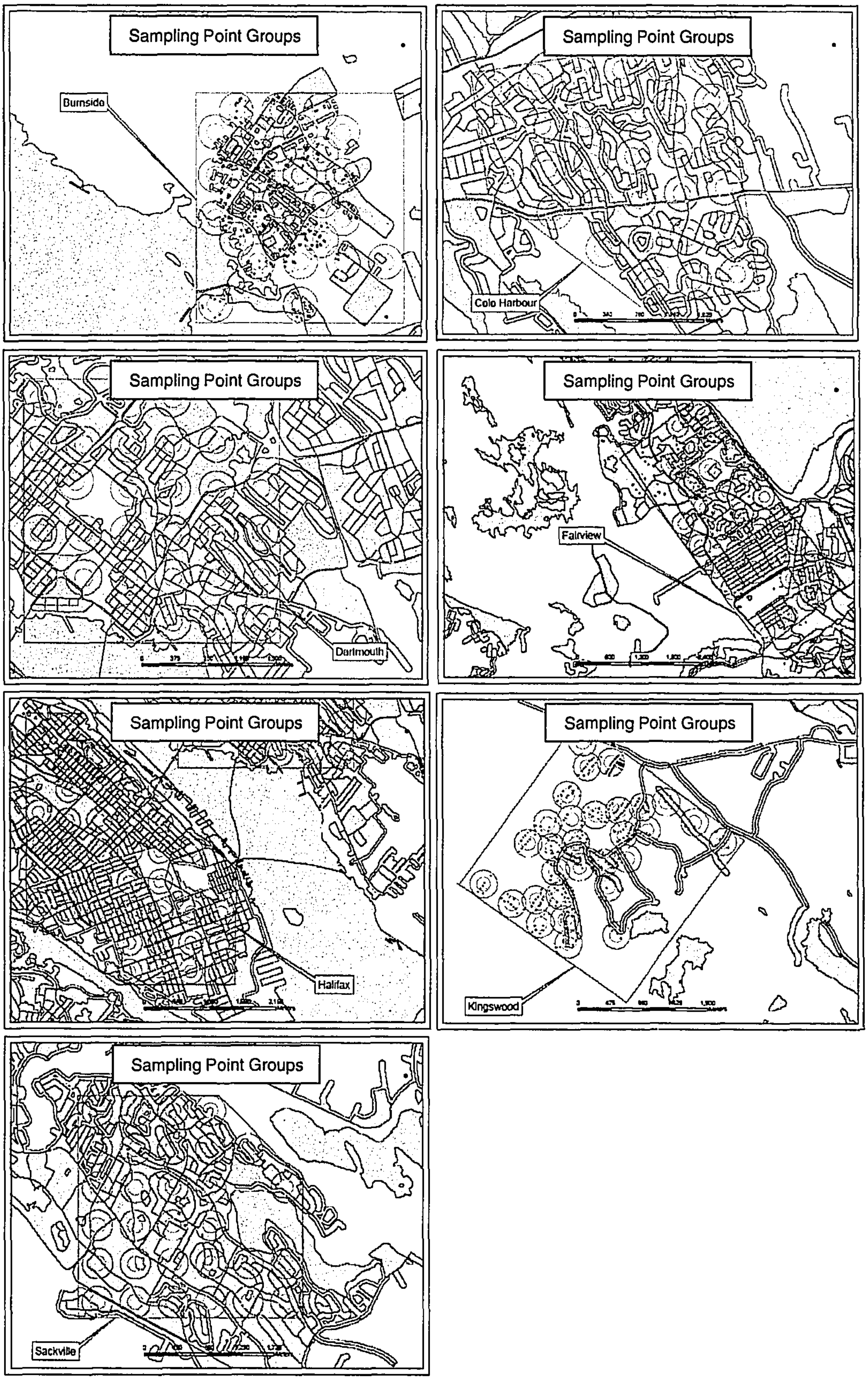
As shown in Figure 3-2, both Halifax peninsula (called "Halifax" for short in the later chapters) and Dartmouth districts attempt to characterize older inner city areas developed from 1749 to approx. 1950 (except the Northern part of Dartmouth was developed after 1950s); Mainland North district (called "Fairview" in the later chapters for short) reflects mixed urban form features of the earlier suburban development, where Fairview area was developed in the 1940s and 1950s, the Clayton Park area was built in the 1960s and early 70's, and the Clayton Park West has been developed from1975 until the present day; Sackville and Cole Harbour districts were included to capture characteristics of carefully planned areas developed after 1963; the Kingswood district represents an exurban development (i.e. large unserviced lots) after 1980; finally, the Burnside district is a large industrial park developed in phases since the early 1960s.

Sampling points and circles

The placement of these sampling points was guided by three principles:

1) To get a sufficient sample size (more than 30 points in each district) for reliability of statistical analysis.
2) To scatter sampling districts widely throughout the built-up area.
3) To keep the entire shape of each district as compact as possible.

Figure 3-3 Sampling circles in the research



Sampling points were located evenly on a grid lattice with a 500m interval inside most districts. Then, sampling circles were created with two radii - 100 meters and 200 meters - using these points as the center. Only those circles that contained a minimum amount of developed area (at least 30% of the circle developed, where "developed" was defined as the presence of streets and buildings) were used in the analysis. In the Burnside and Kingswood districts, the intervals between adjacent sampling points were varied slightly in an attempt to meet the requirements for the minimum developed area and sufficient sample size. So the circles with 200 meter radius overlapped partly (shown in Fig 3-3). In addition, nine extra points were added in Halifax Peninsula district in order to capture more historical development.

Time periods of development

Based on Hartshorn's 5-stage model of urban evolution in North American (1992), time periods of urban growth in this research were slightly revised and tailored as a 5-stage framework based on availability of both archival and digital maps as follows: 1) Previous to 1900 (Walking/Horse-car Era); 2) From 1900 to 1925 (Electric Streetcar/bus Era); 3) From 1925 to 1950 (Motorbus & Early Automobile Era); 4) From 1950 to 1970 (Early Freeway Era); 5) From 1970 to the present.

Land uses

There are six land use categories used in this research, which are Commercial, Government and institutional, Industrial, Mixed land use, Single Family Residential (SFR), and Multiple Family Residential (MFR). Unfortunately, there is no such a detailed recent land use map available though the DMTI mapping does have a land use layer with different categories. To circumvent this problem, three kinds of digital maps were used to create a land use map for the study. They are the LRIS property maps, HRM zoning maps, and DMTI CanMap®. As mentioned earlier, these maps provide land use data for different time periods. But through careful comparison, a recent composite land use map was created. After geo-processing with GIS, the HRM zoning maps were converted to the new land use map using the following steps: 1) Using building data from LRIS property maps, zoning polygon areas containing building(s) were selected, because only these areas were actually developed at the time of the LRIS mapping; 2) Then, the various local codes used in the zoning map were converted to six broad land use categories as shown above; 3) Finally, the DMTI land use map were overlapped, in order to provide a double-check for the final map.

<u>Coding of sampling circles</u>

Using each sampling point as the centroid, sampling circles were generated with two radii - 100 meters and 200 meters - by GIS buffering tools. All three morphologic elements within a sample circle - streets, lots, and buildings - were selected for this study. The main reason why circles were used as the sampling unit rather than squares or other shapes is that circles will not produce sampling bias relating to orientation of streets or buildings. Circles are also the most compact shape around a given point.

In the literature of empirical studies on urban form, the size of sampling unit varies from 500m x 500m grids to 100m x 100m square, and to 400m radius circle for different research objectives. However, there were two concerns regarding the size of sampling circle in this study as follows: 1) The size of a sampling circle does influence the homogeneity of sampled objects inside, because larger areas may have much more variation in the style, land use, and time-periods of urban development; 2) For morphological measures related to lots and buildings, the requirement of correct sampling procedure is about 30 features or more inside each circle, in order to produce results which are statistically significant. Given these concerns, circles with

100 meter and 200 meter radii were employed, to investigate the effects of circle size. Table 3-2 shows the statistical summary for all the buildings in study area. On average, there is a mean of 26 buildings in each 100 meter radius circle and 69 buildings in each 200 meter radius circle. In addition, it is worth noting that different sampling sizes provide another test for the measures, in that a measure will be considered inappropriate for this study in terms of statistical validity if it is excessively sensitive to change based on size of circles.

Table 3-2 Statistical Description of Building Number

	100m Circle	200m Circle
Mean	26	69
Median	20	63
C.V.	85.458	80.737
Kurtosis	0.521	0.136
Skewness	0.923	0.798
Min.	1	1
Max.	75	271
Sum of Buiidings	4003	15112
Count of Circles	219	219

After these circles were created, their attributes then were coded one by one manually using different categorical groups for the seven sampling districts, five developed times periods, and six land uses. For both sizes of circles, listed below are the decision-making rules which were applied for coding attributes for an individual circle:

1) All the water-body areas inside the circle were excluded. That is, circle area was assigned to land area only.
2) Based on the land use map mentioned previously, a land use which occupies more than 50 percent of the built-up area within a circle will be used as the land use attribute of a circle if there is more than one land use inside a circle; otherwise, the circle will be treated as mixed land use.

3) When coding the five time periods of development, that period which built-up area occupied the biggest portion of the build-up area was selected to represent the developed time of the circle.

4. Measure Definitions

In this study, quantifying urban form at a micro level involves the use of statistical measures that describe density, pattern and morphological features of the three elements - streets, lots, and buildings. As discussed in Chapter 2, there are literally hundreds of metrics developed to analyze urban form. A total of 19 measures were selected and calculated in this research, and they can be divided into the four categories of Building density, Building pattern, Road density and Road pattern. Their definitions are listed below:

1) Building density

<u>Gross building density (GrossDen)</u>

Total number of buildings within a sampling circle divided by sampling circle area (ha) excluding the area of water bodies; The higher the value, the greater the development density.

<u>Net building density (NetDen)</u>

Total number of buildings within a sampling circle divided by sum area (ha) of lots containing buildings.

<u>Gross building coverage ratio (GrossCR)</u>

Sum (m^2) of areas of buildings within a sampling circle divided by sampling circle area excluding the area of water bodies (m^2) ; the higher the value, the greater the land price and land usage density.

Net building coverage ratio (NetCR)

Sum (m^2) of areas of buildings within a sampling circle divided by sum area of lots containing buildings (m^2) .

2) Building pattern

Mean Building Size (MBS)

Average size of buildings within a sampling circle (m^2); MBS is a good indicator of land use, and of property value within the residential category.

Median Building Size (MedBS)

The middle building size (m^2) within a sampling circle in square meters.

Building Size Coefficient of Variation (BScov)

Coefficient of variation of building areas within a sampling circle; It suggests the degree of variation within a data set.

Mean Perimeter-Area Ratio (MPAR)

The mean of each building's perimeter/area ratio; Moudon (1986) and Klug (2004) used this measure in their research regarding land use. Generally, for any given buildings, the smaller the MPAR value, the more compact the shape; higher values mean greater shape complexity or greater departure from simple geometry. However, the problem with this measure is that it is sensitive to mean building size because the same building shape can have a different P\A ratio depending on the building size. For instance, a circular building of radius 10 meters returns a ratio of 0.2, and a circular building of radius 100 meters returns a ratio of 0.02.

Mean Shape Index

This is a better measure of shape complexity; MSI equals the sum of each building's perimeter divided by the square root of the building's footprint area multiplied by 4π, and then divided by the number of buildings. MSI has the theoretical bounds $1<$ MSI

$<\infty$. When a building is circular (the most compact possible planar object) MSI = 1, when a building is square MSI = 1.27, and when a building is a rectangle with a minor-to-major axis ratio of 0.5, MSI = 1.43 (Barnsley et al., 2004 and Sonka et al., 1993). This measure avoids the problem with MPAR, since the same shape yields the same value regardless of area.

Mean Proximity (Prox)

This is a measure of the mean spacing between buildings (m). The nearest neighbor distance of an individual building is the shortest distance to another building. The mean proximity is the average of these distances within a circle.

Mean lot size (MLS)

Average size of lots within a sampling circle (m^2); the smaller the MLS, the higher the land use intensity.

Median lot size (MedLS)

The middle lot size (m^2) within a sampling circle in square meters.

Lot size Coefficient of Variation (LScov)

Coefficient of variation of lots containing buildings within a sampling circle; It suggests the degree of variation within a data set.

3) Road density

Gross road density (GrossRD)

Total street length (m) within a sampling circle divided by sampling circle area (m^2), excluding the area of water bodies.

Net road density (NetRD)

Total street length (m) within a sampling circle divided by sum area (m^2) of lots containing buildings.

Gross Junction Density (GrossJD)

Sum of road junctions within a sampling circle divided by sampling circle area (ha) excluding the area of water bodies. Here, a junction means a node where at least three road segments meet (a segment is a line between a From node and a To node).

Net Junction Density (NetJD)

Sum of road junctions within a sampling circle divided by sum area (ha) of lots containing buildings.

4) Road pattern

Road Junction Frequency (JuncF)

Total number of junctions divided by total street length (m) within a circle - This indicator supplies some information regarding cost efficiency and safety (Millward, 1975).

Road connectivity (RoadConn)

Total number of junctions divided by Number of road segments within a circle - For traffic flow safety, the fewer road sections per junction the better (Millward, 1975). Here, a segment means a line between a From node and a To node.

5. Software applied in this study

Data processing in this research can be separated into three steps: 1) data collection, 2) measure calculation and 3) statistical analysis. For the first step, the GIS software package, ArcGIS (including Arcview3.2 and ArcInfo8.3) was used because of its availability and free accessibility. However, this software by itself was unable to generate statistics that measured and quantified the three elements of urban form.

Thus, in the second step, another software package was required that could use polygon shapefiles created by ArcInfo8.3 as input to generate useful metrics for lots and buildings. There are now several commercial and public domain GIS-based software packages available. Among them, two shape measuring software packages were investigated and assessed for their functionality, cost, and applicability. FRAGSTATS*ARC is a software package designed specifically to generate statistics that measure the compactness, complexity, connectivity and fragmentation of shape (FRAGSTATS*ARC Manual, 2000), and seemed very promising as it could be fully integrated with ArcInfo8.3. But, it was also very expensive to purchase. Fortunately, an extension for ArcView 3.2, called Patch Analyst3.1 (Rempel, 2005), was discovered, and was capable of generating the same statistics as those generated by FRAGSTATS*ARC. It was created by the same programmer, but for the earlier GIS package. This extension may be downloaded for free and can be used, along with ArcView 3.2, to generate the preliminary metrics related to lots and buildings.

For calculating Mean Proximity, V_LATE 1.0 (Vector-based Landscape Analysis Tools - an extension for ArcGIS8.3) was employed because Patch Analyst could not provide the proximity calculation with vector data at the time. This extension was created by the SPIN project (Spatial Indicators for European Nature Conservation, 2001-2004) using the same definition for its metrics as Patch analyst. For measuring the street features (polyline shapefiles), RoadCal - a VBA script created by the author - was used to obtain the needed metrics. This particular extension can deal with the polyline shapefile without any help from topological information. Based on the geometry of road segments, it can "automatically" recognize road segments, junctions, and their X, Y coordinates within any given sampling circle. RoadCal can count total length of segments, total number of junctions, and total number of segments inside a circle and supply them in the DBF tables. The script can be found in Appendix-2. Another extension (FieldCal) for GIS was also used to summarize the descriptive statistics for a numerical field (say column

A) using the categorical attributes of another field (say column B) for grouping. Then, all these metrics generated by Patch Analyst and RoadCal were input into MS-excel as raw data for calculating the measures defined in the above section.

In the final step, SPSS was introduced for statistical analysis because it provides all the required statistical procedures for this research. Key manipulations in three software packages are described separately in the following sections and more detailed instructions for ArcGIS, Patch Analyst, RoadCal, and SPSS operation can be found in the following chapters.

6. Data collection with ArcGIS

Figure 3-4 illustrates the simplified and summarized steps. There are seven interrelated steps in this procedure as follows:

Step 1 Data preparation

Initially, 1:1000 and 1: 2000 LRIS property maps were obtained as more than 200 zipped interchange files. Using WinZip and ArcToolbox, they were transformed into coverage files. The field names in all the arc layers were examined and calibrated under a uniform naming standard in order to merge these individual maps to one coverage map. All the building polylines in this coverage map were then selected and exported as a polyline shapefile. Using ET GeoTools8.3 (a free extension for ArcGIS), it was converted to a polygon shapefile, which presents all the buildings in the study area. Fortunately, the lot subdivision map is a polygon shapefile, which can be used directly. All the collected history maps were scanned at 150 dpi and geo-referenced for the next processing step.

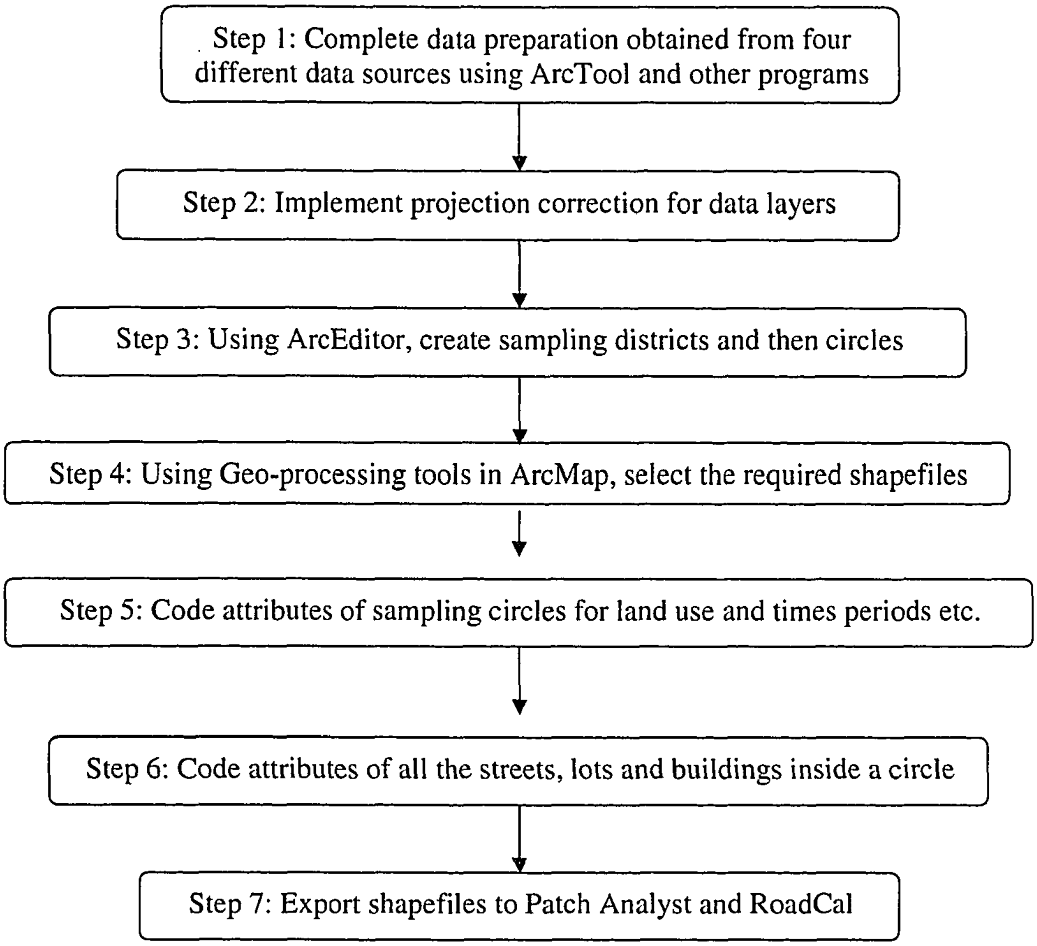


Figure 3-4 Data collection processing

Step 2 Projection corrections

Since the digital maps obtained came from various sources, their projection systems were not uniform. In this study, the MTM (zone5) coordinate system with ATS1977 datum was used for every map. Using ArcCatalog, all the digital maps were checked and their coordinate systems were transformed to the same system.

Step 3 Sampling site placement

Using ArcEditor, seven sampling districts were located and the exact sampling points were placed inside the districts according to the three principles described previously. Then circles were created around sampling points with the buffering tool and their locations were examined carefully to confirm that at least 30 % or more of each circle was developed area.

Step 4 Geo- processing for new map layers

Using the clip tool, circles were imposed on the building layer and lot layer (LRIS data), the street layer and land use layer (DMTI data), and the zoning layer (HRM planning data) to select the required features inside the circles. These selected features were exported as the new shapefiles. Then, in the new building layer, using SQL for selection, all the buildings sharing the same lot FID (Feature Identification Number) with other larger buildings and having a small footprint area (≤ 40 m^2) were excluded since they were usually considered as sheds and garages. Using this layer and the selection tool, the lot, land use, and zoning layers were filtered again to exclude the polygons without buildings or containing small buildings (Footprint area ≤ 40 m^2). In these new layers, those attributes which were not related to this research were deleted. In addition, the polygons of water bodies were removed from the sampling circles by the clipping tool. Finally, zoning codes in the attribute table of the HRM zoning map were converted to six broad land use categories and examined carefully.

Step 5 Coding the circles

The attributes on land use and time periods of development of circles were coded one by one according to the procedure described in the previous section using ArcEditor. For coding the time periods of development, visual inspection was applied to the geo-referenced archival maps. By an evenly cut circular template (like a pie chart), the proportion of area developed could be estimated.

Step 6 Coding the features

Using geo-processing tools, all the feature layers (such as streets, lots, buildings etc.) were intersected with the circles, so that all features inside a circle were given the same circle Identification Number, which was a prerequisite of Patch Analyst and other GIS extensions.

Step 7 Data export

Data were exported to other programs, including Patch analyst, RoadCal and FieldCal etc.

7. Measure calculations

In this step, different polygon (lot and building) and polyline (street) shapefiles were imported into relevant GIS-based extensions including Patch analyst, RoadCal and others. In general, these extensions could only provide raw data which were used to generate the measures for this research. Their outputs were then exported to MS-Excel. Finally, according to the definitions of measures, MS-Excel was used to make proper calculations for these composite measures.

8. Data processing procedure with SPSS

Beginning with this step, research attention shifted to the processes underlying urban development. All the measures for each sampling circle were imported to SPSS for statistical analysis. Outlined below are statistical methods applied in sequence:

1) Bivariate Correlation between all pairs of measures was calculated. Then, those parts of measures with high values of Pearson Correlation were viewed as exhibiting redundancy, so that one of the pair was deleted. The total number of measures was reduced to 12 rather than 19 at the initial stage. Notably, only the linear relationship between two measures was revealed here. Non-linear relationship was discussed under step 3 below.

2) Descriptive statistics such as mean, median, standard deviation, coefficient of variation, skewness and kurtosis etc. were calculated. Then a nonparametric test, the Mann-Whitney test, was employed for determining whether the values of a particular measure differ on average between two districts at a certain confidence level.

3) Several measures were selected for analysis of the bivariate interrelationship. Using logarithmically transformed data, Curve Estimation was employed to produce regression statistics regarding the selected measures which are related to the change rate on the density and size. Then several pairs of measures with high R^2 value were chosen to plot scatter graphs. Allometric interrelationships among these pairs of variables were explored using different plotting schemes.

4) Principal component analysis, a form of factor analysis, was employed using both original data and logarithmically transformed data for the selected measures. The results produced by the two data sets were examined in order to interpret the components. Then, the factors attained from one of two data sets were used for scatter plot analysis, which was useful for modeling the similarity among categorical groups such as different sampling districts. That is, scatter plot analysis can provide quantitative measurements for comparing urban development styles among the sampling districts.

Chapter - 4 Univariate and bivariate descriptive statistics

Having followed the statistical procedures outlined in chapter 3, outcomes derived from univariate and bivariate statistical processing were obtained. Tables 4-1, 4-2, and 4-3 show correlations between measures using the two data sets derived from sampling circles with two different radii. Tables 4-4, 4-5, and 4-6 show descriptive results using data derived from sampling circles with 100 meter radius in three different categorical groups (i.e. seven sampling districts, six land uses, and five time periods of development). Tables 4-7, 4-8, and 4-9 show descriptive results using data derived from sampling circles with 200 meter radius in the three different categorical groups.

1. Results of Bivariate correlation analysis

Table 4-1 shows Pearson correlation coefficients, which are significant at the 0.01 or 0.05 levels (2-tailed) among pairs of measures using data derived from sampling circles with 100 meter radius. Several pairs of measures have high correlation coefficients (more than 0.8), suggesting relatively strong linear relationships, and thus suggesting similar implications in urban growth study. Statistically, one measure in such a pair will be considered as a redundant variable in this study. Thus, measures shadowed in the first row of Table 4-1 will not be discussed in the following assessment since not only were they highly correlated with measures shadowed in the first column of Table 4-1, but also they were regarded as less meaningful for study of urban growth. However, there was an exception for Mean Building Size (MBS) and Median Building Size (MedBS), which had a moderate correlation coefficient of 0.701 (Pearson's). Since MedBS has been extensively used in the literature, MBS was not returned for further processing. Also, Net Road Density (NetRD) and Net Junction Density (NetJD) have a correlation coefficient of 0.794; Gross Junction Density (GrossJD) and Road Connectivity (RoadConn) have a correlation coefficient of 0.771. The one reason is that the same variable (Junctions per sampling circle) was used to compute these composite measures.

Table 4-2 shows Pearson correlation coefficients which are significant at the 0.01 or 0.05 levels (2-tailed) among pairs of measures using data derived from sampling circles with 200 meter radius. Interpretations and measure selection are the same as for the above analysis. Contrary to the correlation statistics with 100 meter radius circle, Mean Building Size (MBS) and Median Building Size (MedBS) have an extremely high correlation coefficient of 0.966 (Pearson's), so that MedBS was used in the next step naturally. Interestingly, and perhaps counter-intuitively, Gross Junction Density (GrossJD) and Road Connectivity (RoadConn) had a lower correlation coefficient (0.557) compared to the 100 meter radius circle (0.771). Gross Building Density (GrossDen) and Gross Road Density (GrossRD) saw a fairly strong correlation coefficient of 0.790 as well.

Table 4-3 shows Pearson correlation coefficients, which are all significant at the 0.01 level (2-tailed), between two groups of measures using two data sets derived from sampling circles with 100 meter and 200 meter radii. Only correlations of the same measures are of interest here. The shadowed measures (NetDen2 and NetCR2) obtained from circles with from meter radius have high correlation coefficients of 0.892 and 0.869 with those for 100m circles. Thus they were considered as redundant variables and are not considered in further analysis.

Table 4-1 Pearson Correlations of Measures (Circles with 100 meters radius)

	PROX	GROSSDEN	NETDEN	GROSSCR	NETCR	MBS	MEDBS	BSCOV	MSI	MPAR	MLS	MEDLS	LSCOV	GROSSRD	NETRD	GROSSJD	NETJD	JUNCF	ROAD CONN
PROX	1																		
GROSSDEN	-.464(**)	1																	
NETDEN	-.520(**)	.858(**)	1																
GROSSCR	-.214(**)	.355(**)	0.13	1															
NETCR	-.261(**)	.305(**)	.262(**)	.874(**)	1														
MBS	.297(**)	-.351(**)	-.438(**)	.479(**)	.500(**)	1													
MEDBS	.152(*)	-.260(**)	-.316(**)	.317(**)	.304(**)	.701(**)	1												
BSCOV	-0.062	0.032	-0.105	.581(**)	.505(**)	.234(**)	-0.002	1											
MSI	0.127	-0.026	-0.041	.316(**)	.345(**)	.355(**)	.279(**)	.274(**)	1										
MPAR	-.238(**)	.474(**)	.611(**)	-.147(*)	-.151(*)	-.566(**)	-.509(**)	0.027	.229(**)	1									
MLS	.291(**)	-.466(**)	-.559(**)	-0.034	-0.124	.468(**)	.365(**)	0.002	.257(**)	-.380(**)	1								
MEDLS	.203(**)	-.395(**)	-.463(**)	-0.11	-.185(**)	.292(**)	.303(**)	-0.083	.182(**)	-.305(**)	.925(**)	1							
LSCOV	-0.132	.145(*)	-0.023	.410(**)	.312(**)	0.067	-0.028	.674(**)	.198(**)	0.116	-.204(**)	-.314(**)	1						
GROSSRD	-.242(**)	.606(**)	.553(**)	.386(**)	.392(**)	-.172(*)	-.156(*)	.218(**)	0.071	.270(**)	-.340(**)	-.312(**)	.194(**)	1					
NETRD	-0.117	-0.056	.231(**)	-.154(*)	-0.014	-0.131	-0.102	-0.115	0.074	.340(**)	-.169(*)	-.139(*)	-0.121	.186(**)	1				
GROSSJD	-.171(*)	.360(**)	.342(**)	.321(**)	.352(**)	-0.088	-0.11	.281(**)	0.096	.175(**)	-.205(**)	-.218(**)	.221(**)	.800(**)	.168(*)	1			
NETJD	-0.105	0.019	.244(**)	-0.046	0.077	-0.106	-0.099	0.016	0.094	.328(**)	-.167(*)	-.156(*)	-0.012	.377(**)	.794(**)	.518(**)	1		
JUNCF	-.139(*)	.270(**)	.281(**)	.260(**)	.320(**)	-0.097	-.148(*)	.324(**)	0.091	.169(*)	-.170(*)	-.179(**)	.223(**)	.643(**)	.172(*)	.877(**)	.503(**)	1	
ROADCONN	-.133(*)	.317(**)	.339(**)	.238(**)	.297(**)	-.147(*)	-.174(*)	.266(**)	0.027	.185(**)	-.244(**)	-.232(**)	.159(*)	.671(**)	.205(**)	.771(**)	.473(**)	.922(**)	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 4-2 Pearson correlations of Measures (Circles with 200 meters radius)

	PROX2	GrossDen2	NETDEN2	GROSSCR2	NETCR2	MBS2	MEDBS2	BSCOV2	MSI2	MPAR2	MLS2	MEDLS2	LSCOV2	GROSSRD2	NETRD2	GROSSJD2	NETJD2	JUNCF2	ROADCON2
PROX2	1																		
GrossDen2	-.587(**)	1																	
NETDEN2	-.689(**)	.803(**)	1																
GROSSCR2	-.393(**)	.514(**)	.216(**)	1															
NETCR2	-.348(**)	.227(**)	.245(**)	.786(**)	1														
MBS2	.197(**)	-.272(**)	-.340(**)	.193(**)	.387(**)	1													
MEDBS2	0.131	-.208(**)	-.256(**)	0.123	.300(**)	.966(**)	1												
BSCOV2	-.204(**)	0.008	-0.08	.420(**)	.364(**)	-0.011	-0.1	1											
MSI2	0.08	-.233(**)	-.352(**)	.318(**)	.295(**)	.254(**)	.170(*)	.303(**)	1										
MPAR2	-.508(**)	.552(**)	.652(**)	-0.131	-.335(**)	-.673(**)	-.582(**)	0.09	-.293(**)	1									
MLS2	.331(**)	-.302(**)	-.374(**)	-0.109	-0.111	.430(**)	.414(**)	-0.024	.171(*)	-.360(**)	1								
MEDLS2	.296(**)	-.244(**)	-.299(**)	-0.106	-0.102	.406(**)	.415(**)	-0.088	0.112	-.336(**)	.974(**)	1							
LSCOV2	-.369(**)	.148(*)	0.058	.263(**)	.140(*)	-0.132	-.150(*)	.542(**)	.181(**)	.266(**)	-.189(**)	-.223(**)	1						
GROSSRD2	-.423(**)	.790(**)	.471(**)	.590(**)	.245(**)	-.172(*)	-.144(*)	0.077	-0.041	.305(**)	-.219(**)	-.180(**)	0.124	1					
NETRD2	-.384(**)	.316(**)	.575(**)	0.042	.232(**)	-.203(**)	-.156(*)	-0.023	-.147(*)	.307(**)	-.264(**)	-.210(**)	-0.035	.464(**)	1				
GROSSJD2	-.444(**)	.682(**)	.465(**)	.566(**)	.305(**)	-.169(*)	-.146(*)	.139(*)	0.068	.304(**)	-.233(**)	-.201(**)	.173(*)	.890(**)	.498(**)	1			
NETJD2	-.428(**)	.366(**)	.545(**)	.197(**)	.294(**)	-.192(**)	-.157(*)	0.069	-0.005	.304(**)	-.258(**)	-.217(**)	0.061	.514(**)	.822(**)	.747(**)	1		
JUNCF2	-.475(**)	.371(**)	.422(**)	.329(**)	.280(**)	-.180(**)	-.160(*)	.216(**)	0.132	.299(**)	-.247(**)	-.228(**)	.246(**)	.431(**)	.426(**)	.718(**)	.780(**)	1	
ROADCON2	-.428(**)	.368(**)	.428(**)	.261(**)	.203(**)	-.155(*)	-0.11	0.109	0.012	.276(**)	-.188(**)	-.136(*)	0.119	.397(**)	.430(**)	.557(**)	.636(**)	.841(**)	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Table 4-3 Pearson correlations between 2 groups of sampling circles												
200m \ 100m	PROX	NETDEN	NETCR	MEDBS	BSCOV	MSI	MPAR	MEDLS	LSCOV	NETRD	NETJD	JUNCF
PROX2	.737(**)											
NETDEN2		.892(**)										
NETCR2			.869(**)									
MEDBS2				.500(**)								
BSCOV2					.659(**)							
MSI2						.398(**)						
MPAR2							.669(**)					
MEDLS2								.608(**)				
LSCOV2									.647(**)			
NETRD2										.325(**)		
NETJD2											.438(**)	
JUNCF2												.560(**)
** Correlation is significant at the 0.01 level (2-tailed).												
* Correlation is significant at the 0.05 level (2-tailed).												

2. Descriptive statistics and difference nonparametric test

Descriptive statistics should enable one to understand the shape of a variable's distribution, particularly regarding the degree of variation. However, tests of the significance of statistical differences would also be useful for determining whether or not the values of a particular measure differ between two groups on average, even if the statistical indices appear similar. A non-parametric two-sample test of differences was used to perform the calculation. Since both Mann-Whitney and Wilcoxon U always return the same results, it was decided to employ the former. This test is called nonparametric because there are no assumptions made that the sample is drawn from a normal distribution. Thus, it is perfect for this study, since the data distributions are frequently not normal.

In total, 92 pairs of measures in three categorical groups (district, land use, and time period) were tested with this method for each of the sampling circle sizes. The two-tailed significance levels resulting from these tests were compiled and can be found in Appendix-1 for the reader's reference. The hypotheses will be accepted at the 0.01 and 0.05 significant levels in this study.

Because of the reasons described in the first section of this chapter, a total of 10 measures were selected to represent urban form on the four measure categories of Building Density (NetDen and NetCR), Building Pattern (Prox, MedBS, MSI, MPAR, BScov, LScov and MedLS), Street Density (NetRD and NetJD), and Street Pattern (JuncF). The statistical descriptors for the measures - mean, median, standard deviation, coefficient of variation, skewness, std. error of skewness, kurtosis, and std. error of kurtosis - were calculated separately for each grouping category.

However, it should be noted that the number of cases, particularly for land use and time period categories, were sometimes too small to produce accurate and meaningful statistics. For example, there are only 7 cases of Multiple Family Residential land use for 200 meter radius circles. The limitation of having inadequate cases on which to perform the calculations is recognized, but there are still some highly significant differences revealed.

In general, the Coefficient of Variation is used to suggest the degree of internal variation within groups, and the degree of homogeneity or heterogeneity of measures used in this study (Millward, 1975). Although skewness and kurtosis were also calculated, these higher-order parameters are more difficult to interpret and are not discussed in the text.

Description of measures for 100 meter radius circles

As shown in Table 4-4, Table 4-5, and Table 4-6, some descriptive statistical indices of the selected measures seem to vary across categorical groups, while others do not. At this stage, no attempt was made to weigh any of the measures in terms of their importance for urban form. The study focuses on differences in the mean, median and Coefficient of Variation for each measure for different categorical groups, since these differences may reflect the capability of each selected measure to capture different characteristics of urban form.

1) Descriptive statistics for sampling districts

Here, the mean, median and coefficient of variation for ten measures in each of seven sampling districts were examined.

Table 4-4 Descriptive statistics (100m) for different sampling districts

		Burnside	Coleharbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville	Total
N		30	30	30	30	39	30	30	219
NetDen	Mean	3.6	11.9	13.2	12.6	13.6	3.1	11.7	10.1
	Median	2.1	12.5	14.7	14.0	11.0	2.6	13.5	9.7
	C.V.	107	48	49	52	65	87	47	73
NetCR	Mean	0.219	0.150	0.209	0.196	0.267	0.045	0.168	0.183
	Median	0.171	0.164	0.211	0.204	0.244	0.038	0.173	0.183
	C.V.	74	39	33	33	41	75	38	61
PROX	Mean	25	11	10	8	8	43	12	16
	Median	24	7	6	7	5	37	7	7
	C.V.	91	115	148	72	124	71	119	127
MedBS	Mean	809	123	234	151	200	140	141	255
	Median	306	108	120	135	124	153	118	123
	C.V.	138	91	185	62	106	24	94	198
BScov	Mean	55	43	62	57	100	21	47	57
	Median	59	22	43	30	76	17	26	32
	C.V.	72	109	79	105	66	62	103	96
MSI	Mean	1.269	1.121	1.243	1.223	1.279	1.189	1.206	1.221
	Median	1.270	1.177	1.219	1.200	1.257	1.184	1.177	1.210
	C.V.	21	28	7	8	6	3	6	14
MAPR	Mean	0.270	0.381	0.384	0.377	0.387	0.358	0.385	0.364
	Median	0.232	0.398	0.399	0.379	0.397	0.349	0.394	0.384
	C.V.	55	33	24	15	19	11	18	27
MedLS	Mean	4734	745	1479	3007	1456	3734	1048	2279
	Median	3434	602	555	624	376	3560	614	631
	C.V.	93	158	214	244	263	39	168	178
LScov	Mean	42	51	67	58	113	26	73	63
	Median	41	34	64	34	105	27	43	41
	C.V.	90	101	79	97	64	57	94	95
NetRD	Mean	0.034	0.030	0.025	0.028	0.023	0.012	0.018	0.024
	Median	0.007	0.019	0.021	0.022	0.020	0.010	0.018	0.019
	C.V.	246	185	75	93	57	81	39	163
NetJD	Mean	0.688	1.301	1.239	1.276	1.202	0.253	0.456	0.928
	Median	0.000	0.623	0.887	0.951	0.998	0.000	0.366	0.514
	C.V.	321	229	163	110	95	167	120	189
JuncF	Mean	0.001	0.003	0.004	0.004	0.005	0.001	0.002	0.003
	Median	0.000	0.004	0.004	0.004	0.005	0.000	0.002	0.003
	C.V.	159	70	82	63	60	146	109	92

Net Building Density (NetDen)

On this measure, the older inner city districts - Halifax and Dartmouth - exhibit a higher mean than the average, as one would expect owing to the greater amount of development with high density prior to the auto-oriented development era (Figure 4-4). Among three suburban districts - Cole Harbour, Fairview, and Sackville - Fairview district has a relatively high mean NetDen of 12.554. The possible reason is that Fairview has the shortest route to downtown areas of Halifax, and this high accessibility brings higher land value and land use intensity than in the other two districts. The exurban district, Kingswood, has a strikingly low mean density of 3.076, which is even lower than in the industrial park, Burnside district. The NetDen values in Halifax district are skewed (comparing mean and median) and have a high C.V., suggesting more heterogeneity in terms of land use, social class, and time of development. In addition, Burnside and Kingswood districts also have a higher value of C.V. than other districts, which reflects spatial clustering or dispersion of development.

Net Coverage Ratio (NetCR)

Generally, NetCR is largely a reflection of land use intensity. Among seven sampling districts, Halifax holds both the highest mean (0.267) and median (0.244) of this measure because central land usually has higher land value and more intense development. Dartmouth and Fairview are almost the same in the value of these statistical descriptors, since they have similar development periods. Cole Harbour and Sackville are both lower, in that they have been developed mostly in the same period (1960s-1980s). The further from the city center, laid the more recently developed, the lower the coverage ratio. In addition, the C.V. of this measure changes only slightly over sampling districts, except for Burnside and Kingswood. Kingswood has by far the lowest value on the mean and median, but the highest C.V. (74.630%), which means both more land consumption in the district and spatial heterogeneity of land consumption. Conversely, though its C.V. value is fairly high at 73.767%, Burnside has moderately high values for mean and median of NetCR.

Mean Proximity (Prox)

As mentioned in Chapter 3, Prox provides the average edge-to-edge nearest neighbor distance (NND) and measures spacing between pairs of buildings. It provides a useful practical indication for development density. Both Halifax and Dartmouth have a higher C.V. value and a lower median value (4.920m and 6.185m respectively) than others areas, suggesting that buildings in these two districts are much closer and NND is variable probably because of the higher degree of mixture of land uses. Interestingly, Fairview has a lower C.V. than other urban areas. This is reasonable, since unlike Cole Harbour and Sackville, which contain large commercial areas, Fairview is most of residential area. Also, planning policies aimed at higher suburban densities were first employed in this area (Clayton Park West). Kingswood has the highest mean of 42.567m and lowest C.V. of 71.448%. This again implies a large amount of land consumption and low degree in land use mixture.

Median Building Size (MedBS)

In general, the value of MedBS in residential areas reflects styles of housing development, and by extension social classes. As shown in Table 4-4, Kingswood has a highest mean of 139.903 m^2 and lowest C.V. of 24.011%, suggesting a prestige housing development. There is also a large median of 134.789 m^2 in Fairview, with a C.V. of 61.609%. Other suburban residential areas have smaller houses and thus lower medians. Cole Harbour's median is particularly low (only 107.8), owing to the rules under which the large community of Forest Hills was developed by the provincial government to qualify for the assisted home ownership (home had to be smaller than a threshold size). Dartmouth has the highest C.V. of 184.872, partly owing to its long history of urban development, in which the urbanized area had spread from the harbour to the entire sampling district by the 1980s. Another reason is that mixture of land uses, which also occurs in the Halifax district. In Burnside, there is a large mean (809.237 m^2) and median (305.795 m^2) of MedBS. This is understandable, since large buildings are used for manufacturing and warehousing.

<u>Mean Shape Index (MSI) and Mean Perimeter-District Ratio (MPAR)</u>

These two measures are interpreted as indicators of shape complexity. It is evident from Table 4-4 that their performances are quite similar. Compared with other measures, their C.V. values remain low because building shapes do not change dramatically within sampling districts. The C.V. value of MPAR is higher than MSI as it is affected by the variable areas of building. The MSI values show buildings in Halifax and Burnside tend to more square than in other areas, which is largely attributable to the presence of non-residential buildings.

<u>Median Lot Size (MedLS)</u>

This measure is widely used to express development density and promoted by advocates of Smart Growth and New Urbanism. Halifax's median value is much smaller that for the other districts, which can be explained by the earlier date of development. Halifax, Dartmouth, and Fairview showed strikingly high C.V. values, implying that there were drastic variations within data sets mainly because of land use mixtures or different housing classes. Kingswood has a much higher median (3559.719m^2) and lower C.V. of 38.933% than other residential areas, owing to the zoning requirement that lots must be at least 0.4 ha in size. Cole Harbour and Sackville had similar median and C.V. values, probably because their growth was controlled by the similar planning policies. Both these areas have huge "planned communities" developed by the provincial government.

<u>Building Size and Lot Size Coefficient Variations (Bscov and LScov)</u>

These two measures are interpreted as indicators of heterogeneity of the sampling circles. The mean and median values reflect the average variation inside the sampling circle. The C.V. value represents the variation among the circles. It is evident from Table 4-4 that performances of two measures are quite similar. Halifax has the highest mean and median values on the two measures, suggesting much more development heterogeneity and mixture of different land uses. Cole Harbour has the highest C.V. value on the two measures as well, which reflects the variation across the area.

Net Road Density (NetRD)

In general, NetRD can be used to evaluate how much of public access are considered in terms of Smart Growth. Halifax, Dartmouth, Fairview, Cole Harbour, and Sackville show very similar median values (about 20 km per square km). Burnside has the lowest median and the highest C.V. values. The possible reason is that NetRD is influenced by the larger lot size and the needs of industrial land uses. As expected, Kingswood also has a fair low median of 10 km per square km, which relates to its "large-lot" development style.

Net Junction Density (NetJD) and Road Junction Frequency (JuncF)

The performances of these two composite measures are similar partly, owing to their use of the same variable (Junctions number within a circle) though they reflect different design and performance concerns. NetJD shows connectivity of streets in a certain area, while JuncF largely reflects layout design and block size (Millward, 1975). Burnside and Kingswood both have lowest medians (near zero) and highest C.V., which means poor connection between streets but smooth traffic flow within sampling districts. Halifax has the highest median value for both measures, suggesting good connection among streets, slow traffic flow, and more intersections as well.

Overall, all the selected measures were variable over different areas in HRM. The comparison of statistical indices allowed meaningful empirical information based on the morphological elements. It should be noted that with a 100 meter radius, the area of a circle is about 0.03 square km (3 ha). Hence, sampling circles of this size might not be fit for capturing street features.

2) Descriptive statistics for land use

Table 4-5 Descriptive statistics (100m) for different land uses

		Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR	Total
N		13	12	31	18	135	10	219
NetDen	Mean	6.2	4.6	3.7	12.3	12.6	4.2	10.1
	Median	6.1	3.4	2.2	10.1	14.4	3.7	9.7
	C.V.	55	91	104	48	58	70	73
NetCR	Mean	0.321	0.222	0.219	0.210	0.153	0.197	0.183
	Median	0.345	0.179	0.171	0.211	0.173	0.199	0.183
	C.V.	45	61	72	30	53	42	61
PROX	Mean	14	24	25	7	16	11	16
	Median	8	20	22	6	7	8	7
	C.V.	105	96	93	52	141	85	127
MedBS	Mean	266	276	796	112	125	540	255
	Median	134	146	375	105	118	224	123
	C.V.	80	113	138	23	57	128	198
BScov	Mean	134	126	56	111	35	68	57
	Median	138	107	61	109	25	64	32
	C.V.	41	54	71	57	96	89	96
MSI	Mean	1.344	1.310	1.269	1.228	1.180	1.349	1.221
	Median	1.326	1.287	1.279	1.225	1.188	1.326	1.210
	C.V.	7	10	21	3	13	9	14
MAPR	Mean	0.336	0.326	0.272	0.402	0.392	0.289	0.364
	Median	0.314	0.329	0.232	0.389	0.394	0.319	0.384
	C.V.	21	23	54	12	20	34	27
MedLS	Mean	1559	4236	5321	456	1569	4306	2279
	Median	630	815	3505	439	613	2054	631
	C.V.	135	208	102	45	174	130	4
LScov	Mean	108	116	40	137	47	97	63
	Median	95	126	41	110	33	104	41
	C.V.	48	56	93	51	97	100	95
NetRD	Mean	0.026	0.016	0.033	0.026	0.023	0.018	0.024
	Median	0.020	0.015	0.007	0.019	0.019	0.018	0.019
	C.V.	105	55	247	86	128	60	163
NetJD	Mean	1.874	0.526	0.680	1.336	0.874	0.949	0.928
	Median	1.265	0.351	0.000	0.916	0.577	0.515	0.514
	C.V.	152	118	319	114	187	142	189
JuncF	Mean	0.006	0.003	0.002	0.004	0.003	0.003	0.003
	Median	0.006	0.003	0.000	0.005	0.003	0.002	0.003
	C.V.	67	90	151	60	85	114	92
* SFR - Single Family Residential								
** MFR - Multiple Family Residential								

Only the medians of selected measures were compared here over different land uses since sampling sizes in some land use categories were not sufficient. As shown in Table 4-5, all the measures experienced detectable changes on the median over different land uses. However, only in Single Family Residential (SFR) and industrial areas, measures have statistically significant statistics because of sample size (30 or more circles used for calculations).

SFR shows the highest median value of 14.4 on Net Building Density (NetDen), but the second lowest value of 0.173 on Net Coverage Ratio (NetCR). Compared with SFR, MFR shows a lower median value of 3.7 on NetDen but a 2% higher value on NetCR, suggesting relatively low land consumption. Compared with SFR Commercial land use has a higher median value of 0.345 on NetCR, reflecting higher land use intensity and land value than other land uses. The C.V. values on NetCR do not vary strongly, owing to the influence of zoning control policies. For Mean Proximity (Prox), Industrial land use has the highest median value of 21.64 m; for Median Building Size in M^2 (MedBS), Industrial area has the highest median value of 375.369 square meter again; and for Median Lot Size (MedLS), industrial area again has the biggest median value. This reflects that large buildings are further apart on the large lots. For Mean Shape Index (MSI) and Mean Perimeter-Area Ratio (MPAR), buildings within Commercial and MFR land use have more complex shape and larger area. For Net road density (NetRD), Industrial areas have the lowest median value of 7 km per square km and the highest value of 247%, suggest the highly uneven street distribution (a reflection of the small sampling circle size); For Net Junction Density (NetJD) and Road Junction Frequency (JuncF), commercial areas have the highest medians of 1.265 and 0.006 respectively, which means there is much more connectivity among streets.

Overall, all the selected measures show variations across different land use subgroups. Thus, it is possible to establish quantitative models for identification and classification of land uses (an important technique for land use mapping) by using these measures.

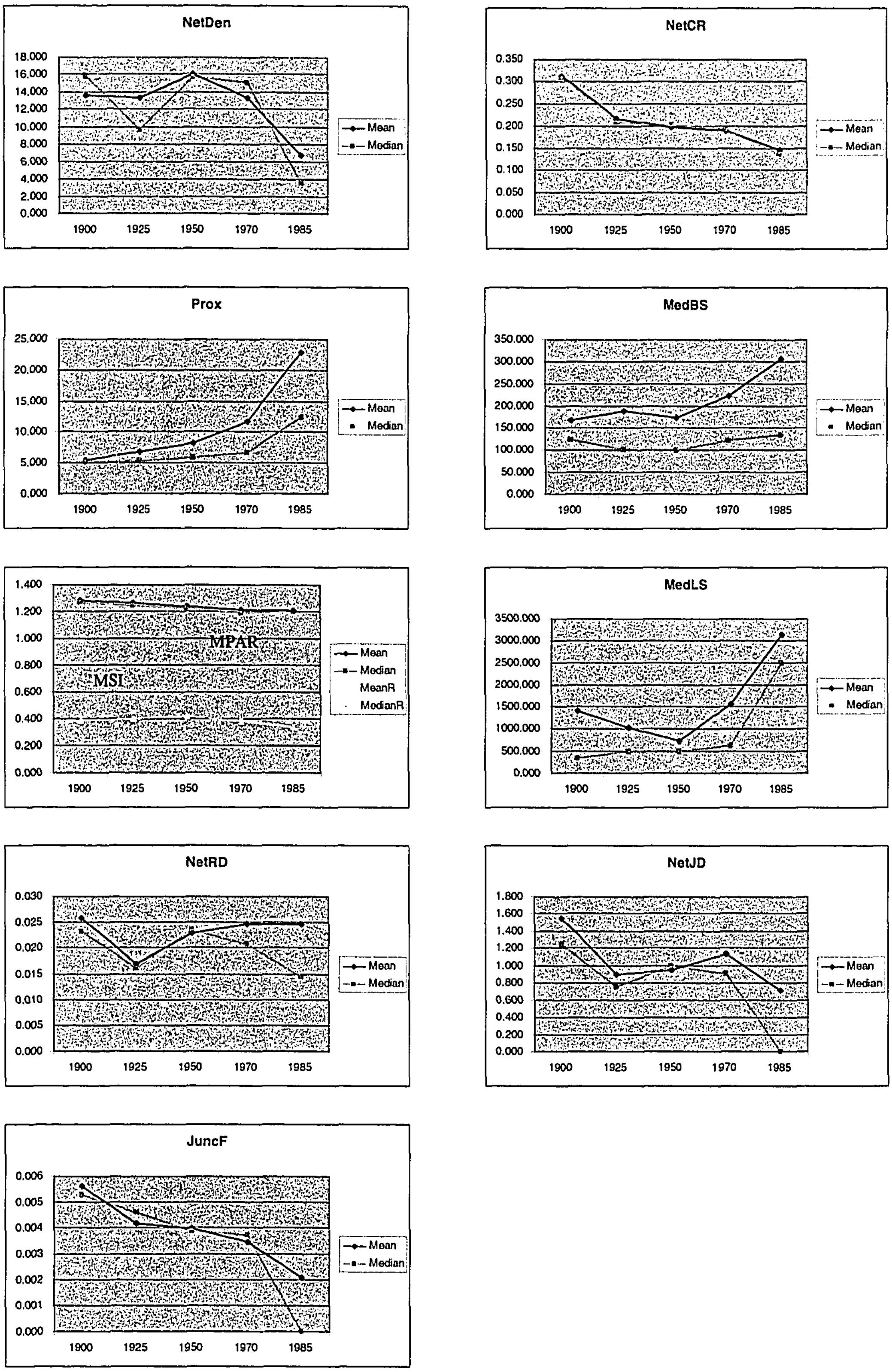
3) Descriptive statistics for time periods of development

Table 4-6 Descriptive statistics (100m) for time period of development

		1900	1925	1950	1970	1985	Total
N		24	11	19	50	115	219
NetDen	Mean	13.6	13.4	16.0	13.3	6.7	10.1
	Median	15.8	9.7	15.7	15.1	3.5	9.7
	C.V.	49	71	53	44	88	73
NetCR	Mean	0.311	0.216	0.197	0.191	0.147	0.183
	Median	0.308	0.210	0.204	0.192	0.137	0.183
	C.V.	35	46	19	24	81	61
PROX	Mean	5	7	8	12	23	16
	Median	5	5	6	7	12	7
	C.V.	65	71	66	125	110	127
MedBS	Mean	167	188	173	223	306	255
	Median	124	101	98	122	135	123
	C.V.	72	115	138	244	189	198
BScov	Mean	115	79	72	53	42	57
	Median	103	67	69	28	27	32
	C.V.	65	69	62	101	98	96
MSI	Mean	1.282	1.262	1.240	1.213	1.205	1.221
	Median	1.267	1.243	1.228	1.186	1.202	1.210
	C.V.	6	5	5	7	19	14
MAPR	Mean	0.388	0.400	0.421	0.381	0.339	0.364
	Median	0.402	0.441	0.414	0.391	0.351	0.384
	C.V.	16	21	16	16	35	27
MedLS	Mean	1408	1018	725	1568	3148	2279
	Median	337	498	503	623	2490	631
	C.V.	329	164	126	285	129	178
LScov	Mean	118	132	76	49	50	63
	Median	114	98	61	33	33	41
	C.V.	49	68	82	74	111	95
NetRD	Mean	0.026	0.017	0.023	0.025	0.025	0.024
	Median	0.023	0.016	0.024	0.021	0.015	0.019
	C.V.	59	50	27	77	213	163
NetJD	Mean	1.546	0.903	0.946	1.132	0.710	0.928
	Median	1.239	0.752	0.998	0.914	0.000	0.514
	C.V.	78	121	66	151	283	189
JuncF	Mean	0.006	0.004	0.004	0.003	0.002	0.003
	Median	0.005	0.005	0.004	0.004	0.000	0.003
	C.V.	34	85	67	78	119	92

As shown in Table 4-6, since the sampling sizes in some categories are not sufficient, only the mean and median of selected measures were compared over different development time periods. Their values were graphed by the lines, suggesting the temporal trends in sampling districts. In Figure 4-1, the lines for mean and median illustrate historical trends for each measure. In general, land use intensity tended to decline through time; Buildings were becoming larger in their area and further apart from each other through time, and they occupied bigger lots than ever before. All three street measures showed decreased road density and decreased junctions along the streets in the study area. It is worth noting that on the NetJD and JuncF, though both group medians at the 1985 time period are zero, when zero values are exclude the medians are 0.322 (junctions per ha) and 0.002 (junctions per meter).

Figure 4-1 Temporal trend of urban development



Description of measures for 200 meter radius circles

Table 4-7, Table 4-8, and Table 4-9 show statistical indices of selected measures across the categorical groups. Again, no attempt was made to weight the importance of any of the measures in terms of their utility in urban form. Here, only differences in the mean, median and Coefficient of Variation of each measure attained from the two sizes of sampling circles were examined, since these differences may reflect the influence of the different sampling schemes and suggest their capability for capturing the different characters of urban form.

1) Descriptive statistics for sampling districts

Comparing with each value in Table 4-4, it is hardly surprising that the mean and median values in Table 4-7 are not much different between the two data sets used for calculations. Only Burnside has an increased median value on MedBS and MedLS, because a circle with 200m radius can entirely contain large buildings and lots now. For Building Size Coefficient of Variation (BScov) and Lot Size Coefficient of Variation (LScov), compared with the result from 100 meter circles, all the districts have increased median values and decreased C.V. values, suggesting that the larger sampling circles not only have more "internal" heterogeneity, but also have more chances to contain the same number of buildings, lots and streets.

The C.V. values on most measures are lower than those in Table 4-4. But there are several exceptions. On the Proximity measure, unlike other districts, Fairview has a slight increase of 11% on the C.V. value, compared with the result from 100 meter circles, suggesting that there is more heterogeneity of development in the area. In contrast to other districts again, Dartmouth has a strikingly increased C.V. value on the MedBS from 185% to 426% when sampling circles turn larger. This partly reflects the huge size of MicMac mall. Similarly, on the MedLS, Dartmouth and Fairview

Table 4-7 Descriptive statistics (200m) for different sampling districts

		Burnside	Coleharbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville	Total
N		30	30	30	30	39	30	30	219
NetDen	Mean	1.7	11.4	11.1	10.9	12.8	2.4	10.8	8.9
	Median	1.5	11.2	12.0	11.3	11.4	2.2	12.2	9.0
	C.V.	45	30	45	49	56	77	42	70
NetCR	Mean	0.230	0.161	0.188	0.180	0.245	0.038	0.161	0.175
	Median	0.234	0.163	0.189	0.187	0.226	0.036	0.157	0.179
	C.V.	58	22	26	26	27	63	32	52
PROX	Mean	30	9	9	10	5	39	9	15
	Median	26	7	7	7	4	38	7	8
	C.V.	50	63	138	82	69	34	76	101
MedBS	Mean	1130	125	624	159	141	157	120	342
	Median	638	115	113	135	112	162	121	128
	C.V.	105	26	426	68	61	15	10	327
BScov	Mean	104	82	100	94	149	25	88	94
	Median	100	59	100	80	131	25	30	81
	C.V.	36	78	64	60	57	33	101	77
MSI	Mean	1.277	1.178	1.237	1.226	1.276	1.196	1.194	1.228
	Median	1.263	1.175	1.213	1.220	1.257	1.191	1.172	1.216
	C.V.	5	2	6	4	5	2	5	5
MAPR	Mean	0.230	0.379	0.381	0.369	0.402	0.349	0.389	0.359
	Median	0.201	0.388	0.408	0.371	0.413	0.342	0.383	0.376
	C.V.	46	7	22	16	15	8	12	23
MedLS	Mean	6378	667	2855	4875	662	4797	744	2901
	Median	4649	622	574	611	365	4650	614	629
	C.V.	80	64	359	468	266	35	71	332
LScov	Mean	83	115	127	125	203	35	154	124
	Median	68	83	107	116	173	30	128	92
	C.V.	64	78	64	61	60	64	81	83
NetRD	Mean	0.012	0.022	0.020	0.023	0.021	0.009	0.017	0.018
	Median	0.009	0.018	0.018	0.020	0.021	0.009	0.017	0.017
	C.V.	74	53	38	53	32	35	29	53
NetJD	Mean	0.369	0.707	0.867	0.936	1.073	0.159	0.501	0.676
	Median	0.235	0.579	0.760	0.754	0.960	0.148	0.520	0.576
	C.V.	128	62	69	66	47	92	60	82
JuncF	Mean	0.002	0.003	0.004	0.004	0.005	0.002	0.003	0.003
	Median	0.002	0.003	0.004	0.004	0.005	0.002	0.003	0.003
	C.V.	83	37	44	34	28	81	49	55

have an increased C.V. value owing to the change on the size of sampling circles. All these changes may also imply that by increasing size of a sampling circle, more heterogeneity development and land use mixture were captured. In Table 4-7, on the NetJD and JunD, the median values of Burnside and Kingswood were positive, whereas processing with 100 meter radius gave zero value because streets were often not present in the small circles. All three street measures (NetRD, NetJD, JuncF) retain similar mean and median values, compared with those in Table 4-4. It is worth noting that the NetRD has an overall mean value of 18 km per km^2, which is similar to Millward's calculation (13.6 km per km^2).

2) Descriptive statistics for time periods of development

Table 4-8 Descriptive statistics (200m) for different land uses

		Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR	Total
N		15	10	31	24	132	7	219
NetDen	Mean	5.7	4.7	1.8	9.3	11.3	6.1	8.9
	Median	4.1	4.8	1.6	8.9	12.4	6.9	9.0
	C.V.	85	82	48	33	55	45	70
NetCR	Mean	0.260	0.202	0.231	0.178	0.148	0.216	0.175
	Median	0.260	0.185	0.235	0.161	0.164	0.206	0.179
	C.V.	35	48	57	30	49	15	52
PROX	Mean	11	20	30	8	14	11	15
	Median	8	10	26	8	7	9	8
	C.V.	104	120	53	51	109	45	101
MedBS	Mean	1149	196	1105	117	126	293	342
	Median	136	168	596	115	122	218	128
	C.V.	326	67	106	19	24	72	327
BScov	Mean	176	187	105	165	62	98	94
	Median	166	182	100	149	35	97	81
	C.V.	50	37	36	43	87	34	77
MSI	Mean	1.290	1.340	1.278	1.222	1.198	1.325	1.228
	Median	1.273	1.326	1.268	1.215	1.191	1.360	1.216
	C.V.	5	6	5	3	3	6	5
MAPR	Mean	0.322	0.350	0.233	0.394	0.389	0.311	0.359
	Median	0.332	0.334	0.208	0.392	0.386	0.316	0.376
	C.V.	29	19	45	10	12	23	23
MedLS	Mean	4553	14362	6179	580	1593	1092	2901
	Median	460	594	4388	560	617	585	629
	C.V.	316	273	83	33	131	79	332
BScov	Mean	174	217	92	200	102	171	124
	Median	163	160	69	182	62	175	92
	C.V.	49	71	79	44	94	52	83
NetRD	Mean	0.018	0.014	0.012	0.017	0.020	0.017	0.018
	Median	0.018	0.012	0.009	0.016	0.018	0.015	0.017
	C.V.	34	52	72	25	53	41	53
NetJD	Mean	0.833	0.539	0.392	0.699	0.737	0.566	0.676
	Median	0.932	0.544	0.259	0.656	0.630	0.304	0.576
	C.V.	71	67	123	40	81	116	82
JuncF	Mean	0.004	0.004	0.003	0.004	0.003	0.003	0.003
	Median	0.005	0.004	0.002	0.004	0.003	0.002	0.003
	C.V.	58	51	82	26	52	96	55
* SFR - Single Family Residential								
** MFR - Multiple Family Residential								

For land use categories, since the data set derived from 200 meter circles still could not supply large enough sampling size, only the values of measures for industrial and SFR land use can be compared in terms of statistical reliability (shown in Table 4-8). Compared with the relevant values in Table 4-5, all C.V. values of measures for industrial and SFR land uses decreased. Most mean and median values of measures for industrial and SFR land uses do not change much, except the median value of MedBS (595 m^2) and MedLS (4388 m^2). It is worth noting that with the increase on size, NetJD and JuncF now show non-zero median values, because at least half the circles contain road junctions. For these variables, circle size clearly does matter.

3) Descriptive statistics for time periods of development

Though there is not sufficient sampling size in several time periods (Table 4-9), it is possible to compare the performance of measures roughly using the median value. Figure 4-2 compares two groups of medians, where "median" was obtained from the data set with 100 meter radius and "median2" was obtained from the data set with 200 meter radius. Despite minor differences in values, the performances of most measure are similar. However, values of "median2" on the NetJD and JuncF are higher values than their counterparts (both values of "median" = Zero).

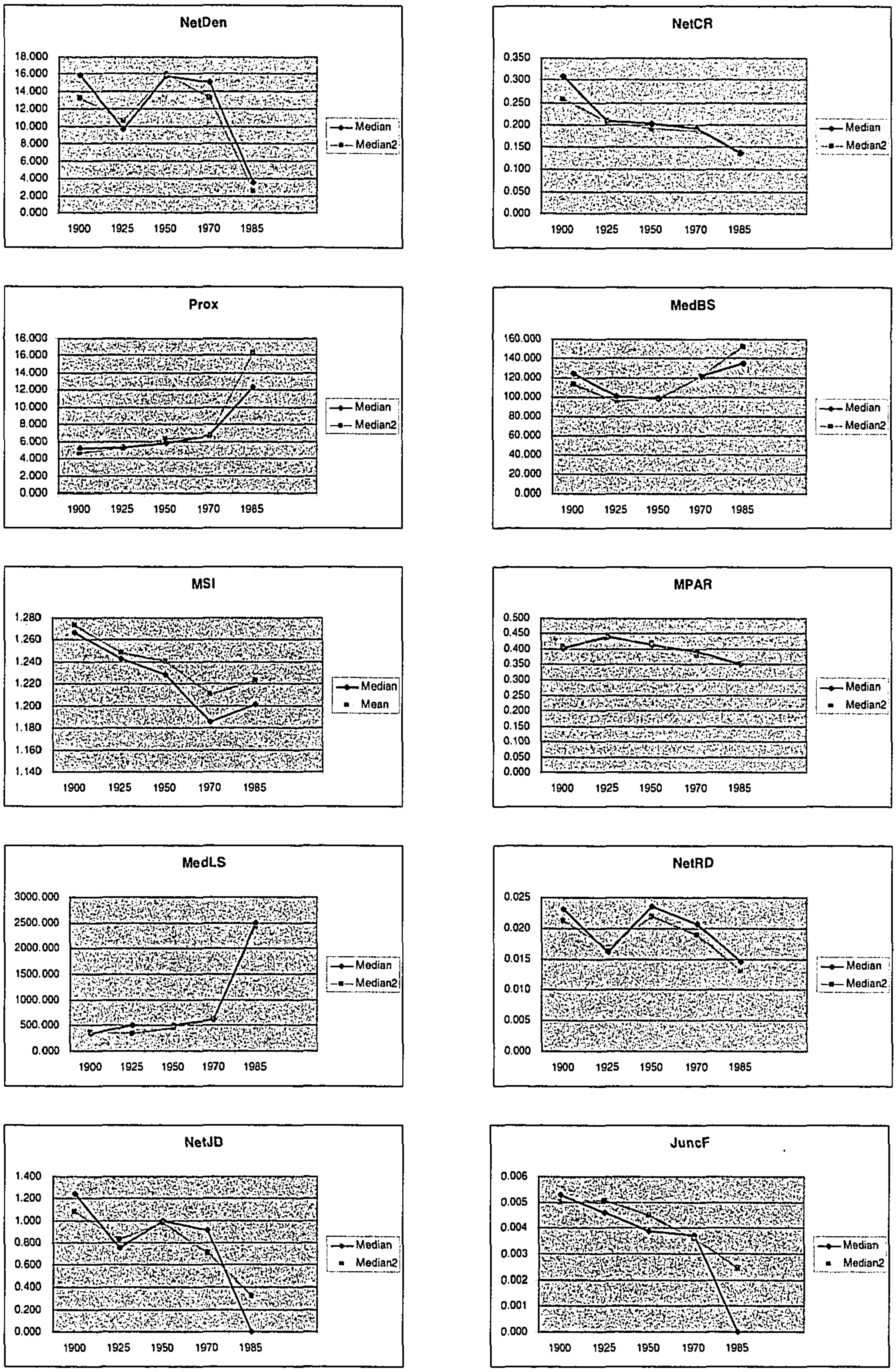
It is noteworthy that values of Median obtained from the two sets of sampling circles have similar historical trends. NetDen, which reflects land use intensity, tends to decline over time; Proximity and MedBS show that buildings became larger and further apart from each other through time, and they occupied bigger lots than ever before. There are two exceptions on NetDen and NetRd. Big drops in median values can be found from the 19^{th} century to 1925. There are two possible reasons: 1) only a total of 11 circles were in this subgroup, so the result is statistically unreliable, and 2) little construction activity occurred during that time period, except for public buildings.

During the 1950s, MedBS has a low value but a high value on NetDen. This is understandable in relation to improving economic conditions: people were enabled to move from rental apartments or boarding houses into owner-occupied single family houses at this time, but they could only afford small houses.

Table 4-9 Descriptive statistics (200m) for time period of development

		1900	1925	1950	1970	1985	Total
N		24	11	19	50	115	219
NetDen	Mean	11.5	12.5	15.3	12.0	5.6	8.9
	Median	13.3	10.6	16.0	13.3	2.6	9.0
	C.V.	44	48	46	43	84	70
NetCR	Mean	0.256	0.216	0.193	0.186	0.147	0.175
	Median	0.258	0.207	0.192	0.187	0.135	0.179
	C.V.	30	29	14	22	71	52
PROX	Mean	5	5	6	10	22	15
	Median	5	5	6	7	16	8
	C.V.	38	41	40	116	77	101
MedBS	Mean	158	103	104	174	516	342
	Median	113	96	98	122	152	128
	C.V.	63	22	33	92	295	327
BScov	Mean	153	157	106	78	80	94
	Median	141	157	93	66	61	81
	C.V.	51	62	55	78	82	77
MSI	Mean	1.273	1.248	1.241	1.211	1.223	1.228
	Median	1.262	1.238	1.224	1.189	1.206	1.216
	C.V.	4	3	4	6	5	5
MAPR	Mean	0.389	0.423	0.434	0.372	0.329	0.359
	Median	0.406	0.435	0.419	0.379	0.351	0.376
	C.V.	14	7	10	15	28	23
MedLS	Mean	366	396	503	3570	3775	2901
	Median	369	335	460	621	2415	629
	C.V.	27	26	30	495	164	332
LScov	Mean	197	253	137	99	104	124
	Median	174	182	103	82	63	92
	C.V.	38	56	85	69	93	83
NetRD	Mean	0.021	0.018	0.024	0.021	0.015	0.018
	Median	0.021	0.017	0.022	0.019	0.013	0.017
	C.V.	30	30	31	49	63	53
NetJD	Mean	1.092	0.927	1.114	0.840	0.421	0.676
	Median	1.084	0.832	0.981	0.707	0.330	0.576
	C.V.	42	49	51	71	99	82
JuncF	Mean	0.005	0.005	0.005	0.004	0.003	0.003
	Median	0.005	0.005	0.005	0.004	0.002	0.003
	C.V.	20	24	36	43	66	55

Figure 4-2 Contrasted temporal trend



Chapter - 5 Allometric interrelationships between measures

Originally, the term allometry was used for the study of differential growth rates of the parts or processes of a living organism's body (EvoWiki.net, 2005). Allometric relationships are usually expressed in power-law form or in a logarithmic form. That is, $Y = aX^{\pm b}$, and both Y and X can be transformed as $\text{Log } Y = \log a \pm b^{*}\text{Log } X$ (alternatively expressed as $Y' = a \pm bX'$), which can be expressed as a straight line on the scatter plot using logarithmically transformed data.

When graphed linearly, two plotted variables reflecting allometric relationship have a particular value on the slope of the fit line because of different dimensionalities of the two data sets. When the slope equals one (or -1), the two have similar rates of change, usually because of similar dimensionality. In contrast to the cause and effect relationship, allometric relationship belongs to the scope of functional relationship, where a set of variables is used to measure different aspects of a large system. In the past decades, several researchers have explored interactions between size, shape, and function using the allometric theory in urban geography. For instance, drawing upon existing urban geographic theories of allometry, Roberts et al (1997) predicted urban densities and population size based on light intensity.

In this chapter, reliance is placed on the use of both Curve Estimation and Scatter Plot in SPSS to investigate allometric relationships among pairs of selected measures.

1. Curve Estimation procedure

Allometric relationship can be found between pairs of variables reflecting different rates of change owing to their different dimensionalities. Usually, these variables are related to density or size issues in urban geography. In this study, six measures were selected for investigations of allometric relationships. They are NetDen (Net Building Density), NetCR (Net Building Coverage Ratio), Prox (Mean Proximity), MedBS (Median Building Size), MedLS (Median Lot Size), NetRD (Net Road Density) since they all measure different aspects of density and size, and have the particular dimensionality as follows:

1) Both Prox and NetRD had the same dimensionality of 1 (1-D), in that they were utilized to characterize lengths between given points;

2) NetDen, NetCR, MedBS, and MedLS had a dimensionality of 2 (2-D), because they reflect change on area for 2-D features (buildings or lots).

It is worth noting that though NetDen was calculated by the number of buildings, it was essentially related to the area of buildings. That is, the larger the building number, the higher the area of building footprint. However, dimensionality is a relative concept and is affected by scale of analysis. That is, at the street block level, a single family house building appears as a 3-D block; but at the large metropolitan level, its dimensionality decreases to zero (just like a dot).

Using the two data sets derived from different circles, all the related original data were first processed to remove cases with one or more zero values in order to apply the power model and then Curve Estimation with linear, quadratic, cubic, and power models was used to discern allometric relationships. In general, the R^2 value quantifies the fitness of model and can be read in percentage terms. The higher the value, the better the fitness. Visual inspection on the graphs generated by Curve Estamaton also helps to determine how the X and Y variables are related. Overall, scrutiny of both R^2 values and graphs shows that for nearly all pairs of variables, the power model returns the highest R^2 value and best characterizes the relationship.

Table 5-1 R^2 values for Curve Fit (100m Circle)

	Model	NetDen	NetCR	MedBS	MedLS
PROX	LIN	**0.348**	**0.087**	**0.099**	**0.330**
	QUA	**0.513**	**0.121**	**0.153**	**0.568**
	CUB	**0.603**	**0.191**	**0.160**	**0.575**
	POW	**0.684**	**0.339**	**0.143**	**0.564**
NETRD	LIN	**0.068**	**0.001**	0.002	0.033
	QUA	**0.156**	**0.011**	0.002	**0.070**
	CUB	**0.199**	**0.012**	0.003	**0.081**
	POW	**0.117**	**0.011**	0.012	**0.096**

* Bold R^2 values: significant at the 0.01 level

Table 5-2 R^2 values for Curve Fit (200m Circle)

	Model	NetDen	NetCR	MedBS	MedLS
PROX	LIN	**0.459**	**0.130**	**0.160**	**0.549**
	QUA	**0.620**	**0.183**	**0.160**	**0.622**
	CUB	**0.694**	**0.183**	**0.182**	**0.622**
	POW	**0.781**	**0.355**	**0.272**	**0.781**
NETRD	LIN	**0.252**	**0.060**	0.025	**0.102**
	QUA	**0.356**	**0.089**	0.042	**0.206**
	CUB	**0.378**	**0.092**	0.049	**0.287**
	POW	**0.348**	**0.170**	**0.074**	**0.265**

* Bold R^2 values: significant at the 0.01 level

Table 5-1 and Table 5-2 show R^2 values of all the variables pairs derived from the selected measures. The R^2 value in **bold** suggests that the correlationship between two measures is significant at the 0.01 level. Note that, the each R^2 value in Table 2 is greater than its corresponding R^2 value in Table 1. This is reasonable, since the data set obtained from circles with 200 meter radius entirely contain the data set obtained from circles with 100 meter radius. That is, R^2 value derived from 100 meter radius circle reflects partially the relationship between two measures. Furthermore, the increased sampling number might enhance the relationship.

2. Scatter plot graphs and interpretations

In this study, the footprint of a typical single family house in the sampling districts is about 120 m^2. It occupies 0.38% of a circle with 100 meter radius, and only 0.09% of a circle with 200 meter radius. Thus, in the 200 meter radius circle, the change in building proximity related to building size is too tiny to detect. In this sense, the dimensionality of the four measures of area decrease in the large circle and they provide a different perspective on the allometric relationship. In fact, it was found in a pilot study for circles with 200 meter radius that the slope values (exponents) between log_prox (Mean Proximity) and other building measures were approached to +1 or -1, suggesting the variables had the same dimensionality. However, as mentioned in chapter 4, the large circle with 200 meter radius is most appropriate for street measures, since it can capture more street features.

Using logarithmically transformed data, each variable pair was broken into the subgroups for scatter plotting by seven sampling districts, six land uses, and five time periods of development. Totally, 304 scatter graphs were generated according to different grouping schemes (using 1-D measures - Prox and NetRD - as X). Overall, most of exponent values shown on graphs vary between +1 to -1, unlike the expected constant proportionality of ± 2.

In this chapter, several plots were selected as the examples to illustrate the changes on the exponents across different subgroups, which might provide more meaningful information regarding urban development trends. The sampling size was reduced after log-transformation, since the data value of zero that occurred only among three street measures could not be transformed. The sampling size of each categorical subgroup varies across different subgroups (shown on Table 5-3 and Table 5-4). So it is necessary to use a two-tailed test for the significance of the correlationship between the pair of measures in the sub-groups when interpreting scatter plots. In this research, values of R were compared with critical-value of R at the 0.05 significance level.

Table 5-3 Cases Used (100m) in Analysis after Logarithmical transformation

Sampling District	Number	Land Use	Number	Time periods	Number
Burnside	8	Commercial	10	1900	23
Cole Harbour	22	Government	8	1925	8
Dartmouth	21	Industrial	8	1950	16
Fairview	23	Mixed Land use	15	1970	36
Halifax	33	Single Family Residential	88	1985	50
Kingswood	10	Multiple Family Residential	4	Total	133
Sackville	16	Total	133		
Total	133				

Table 5-4 Cases Used (200m) in Analysis after Logarithmical transformation

Sampling District	Number	Land Use	Number	Time periods	Number
Burnside	22	Commercial	12	1900	24
Cole Harbour	28	Government	9	1925	11
Dartmouth	27	Industrial	23	1950	18
Fairview	29	Mixed Land use	24	1970	47
Halifax	39	Single Family Residential	119	1985	92
Kingswood	20	Multiple Family Residential	5	Total	192
Sackville	27	Total	192		
Total	192				

A perfect allometric relationship should show as a straight line on the scatter graph. The scatter plots generated by SPSS were edited to display the line of best fit, the value for R^2 (shown as "R-Square" in the graphs), and the regression equation for each categorical group. It should be noted that these the R^2 values varied frequently when the data sets were broken by different categorical groups (subgroups), since R^2 value was sensitive to the variation of sample size obviously. Typically, smaller group had the lower R^2 value. It is also possible that after broken into the subgroups, several pairs of measures might obtain higher R^2 values than their initial values in table 1 or table 2.

In this study, tentative interpretations for scatter plots were centered on the following aspects: 1) to examine the significance using sample number and R-value in each sub-group; 2) to compare the changes of the slope value (exponent) across the subgroups, which imply trends of the change rate within data sets; 3) to explain change trends of the slope (exponent) across subgroups, which may suggests different morphological functional relationships for different groups.

Figure 5-1 shows relationships between two measures (Mean Proximity - log_prox and Net Building Density - log_netd) throughout seven sampling districts. Most of the R-values were significant at the 0.01 level except for Burnside and Kingswood. In Halifax, the slope value (-0.96) suggests the similar dimensionality of two measures. The possible reason is that on average, the size of building footprint is relatively smaller than in other areas, since there are much more residential land use and neighborhood commercial land use. So in comparison to the size of sampling circle, most buildings in Halifax lose their dimensionality and appear as dots. The slope values (exponents) in Fairview and Cole Harbour are similar to the one in Halifax. In Dartmouth, the slope value of -0.45 is greater than the expected value of -2. This is reasonable, since several large retail buildings (particularly MicMac Mall) may influence the rate of change in Net Building Density (that is, less variation on building number inside circles). In Sackville and Kingswood, exponent values at -0.58 and 0.51 suggest fewer changes on the building number in those areas. Overall, the slope value tends to approach -0.5 as moving from city core to periphery, suggesting the impacts of large buildings.

Figure 5-2 illustrates relationships between Mean Proximity (log_prox) and Net Building Density (log_netd) throughout six land uses. The R-values for Mixed land use and Multiple Family Residential are not significant at the 0.05 level. The slope value (-0.38) in industrial land use suggests the difference in dimensionality from others. Figure 5-3 shows relationships between two measures (Mean Proximity - log_prox and Net Building Coverage Ratio - log_netc) in different land use categories. At the 0.05 level of significance, the relationships are valid in three land use categories which are commercial, government, and Single Family Housing. All the slope values in the regression equations vary between -0.5 and -1, reflecting a range of allometric relationships. The range may be attributable to different kinds of layout and design required by different land uses.

As shown in Figure 5-4, only in Cole Harbour and Halifax subgroups, the regression relationships are significant at the 0.05 level between Mean Proximity (log_prox) and Net Median Building Size (log_medb). In Halifax, the exponent is 0.49, while in Cole Harbour, it is evident that the slope value may approach 0.5 if we exclude the extreme points. The positive value of the slope means that larger buildings have a greater spacing than the smaller ones.

Figure 5-5 shows that, as a whole, the relationship between Net Road Density (log_netr) and Net Building Coverage Ratio (log_netc) is significant at the 0.01level. The slope value of 0.52 suggests the allometric relationship. In addition, in Fairview and Sackville districts (Firgure 5-6), allometric relationship at the 0.05 significant levels can be found between these two measures. Their slope values are the same at 0.48, which shows that the layout in these two areas is similar.

Overall, the investigation of allometric relationships between measures provided a unique way to understand these measures of urban form. However, the appropriate sampling method and scope for analysis of allometric relationships requires further study.

Figure 5-1 Scatter plot graph (100m Circles)

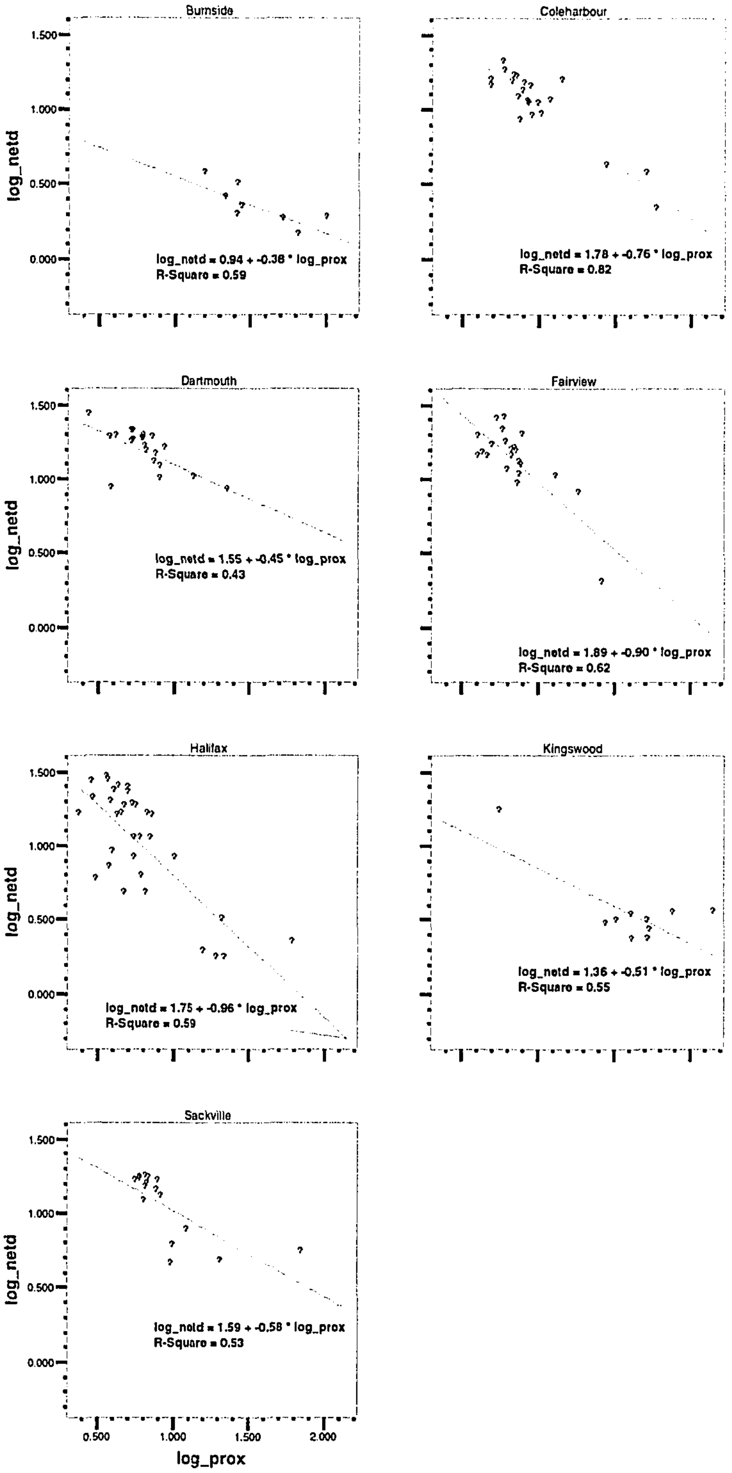


Figure 5-2 Scatter plot graph (100m Circles)

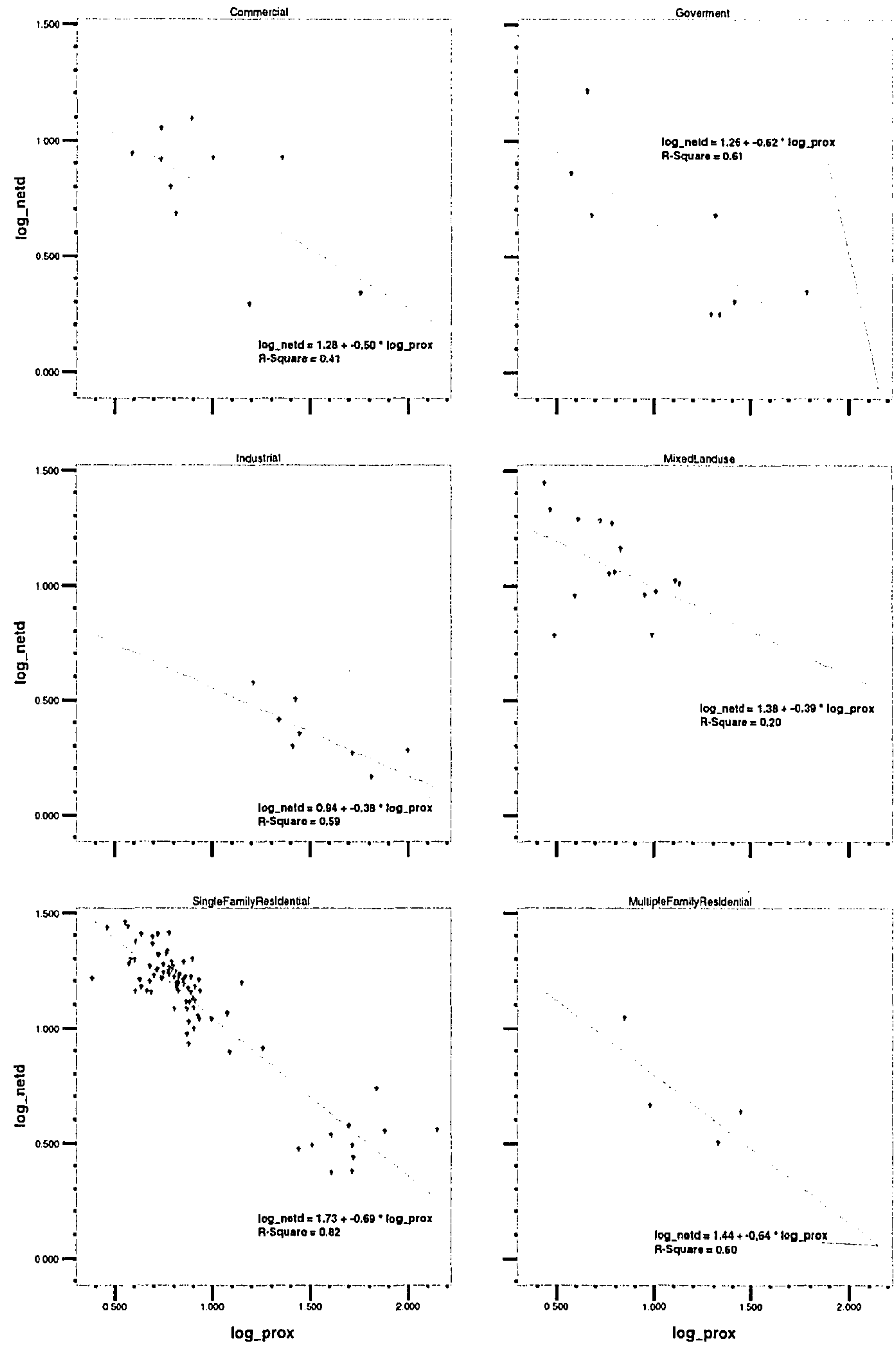


Figure 5-3 Scatter plot graph (100m Circles)

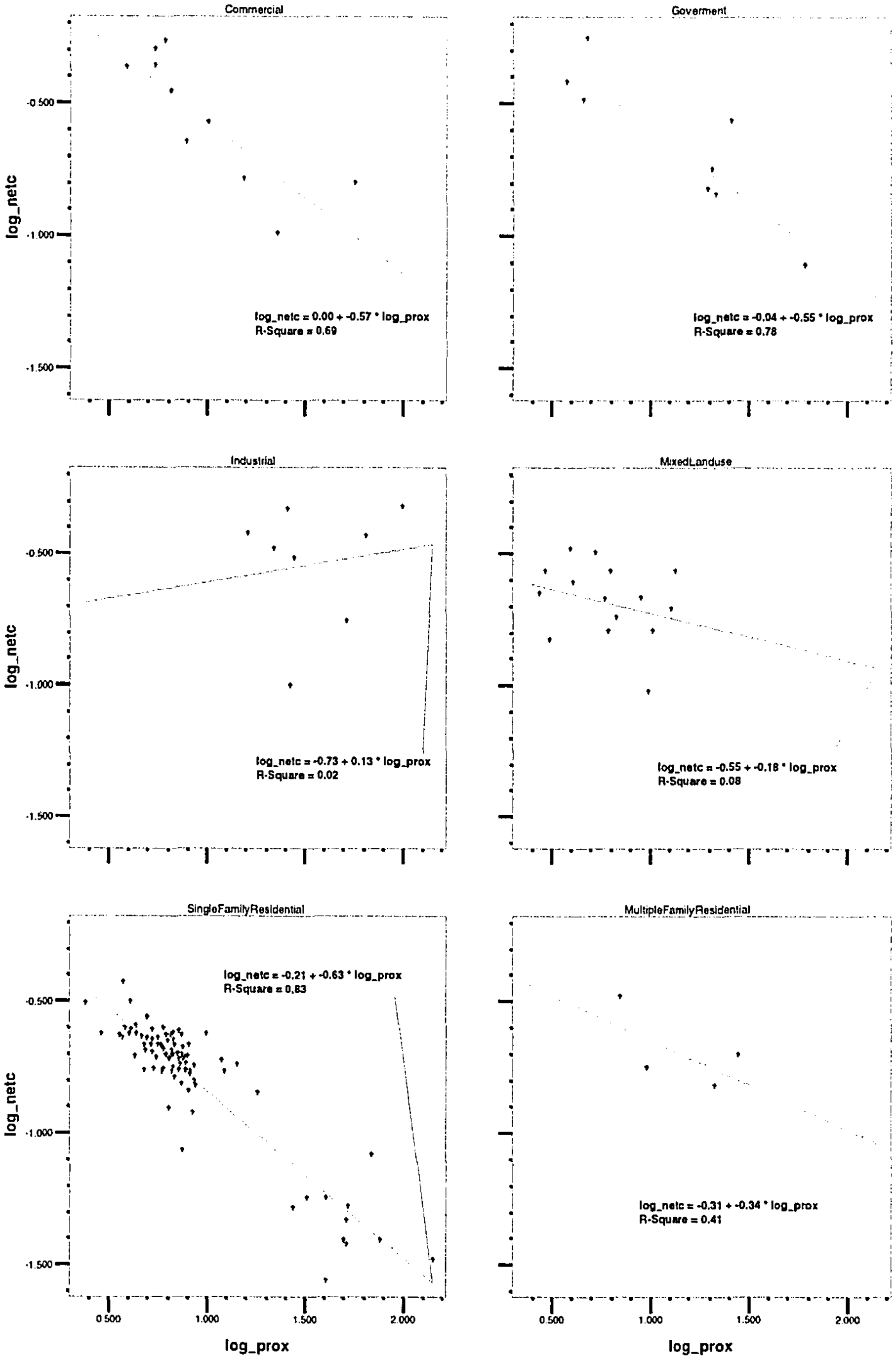


Figure 5-4 Scatter plot graph (100m Circles)

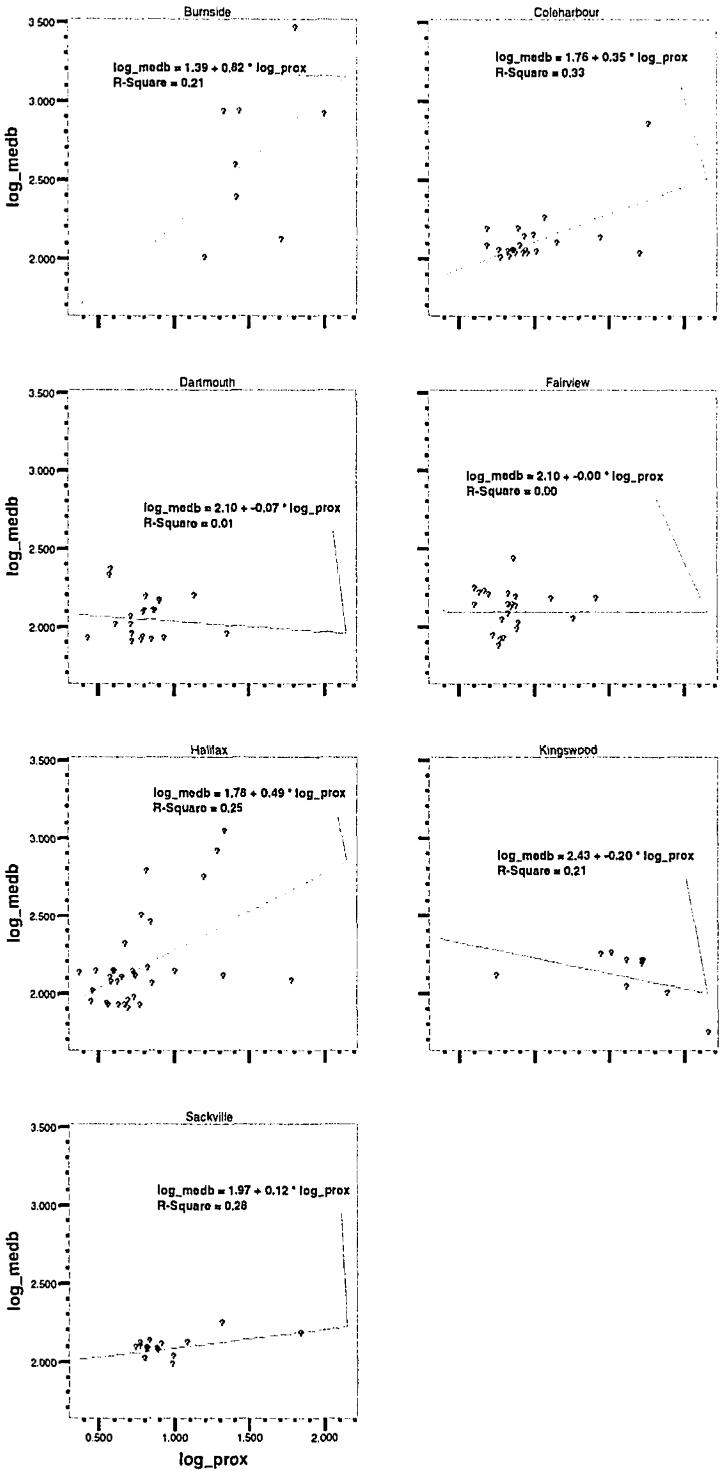


Figure 5-5 Scatter plot graph (200m Circles)

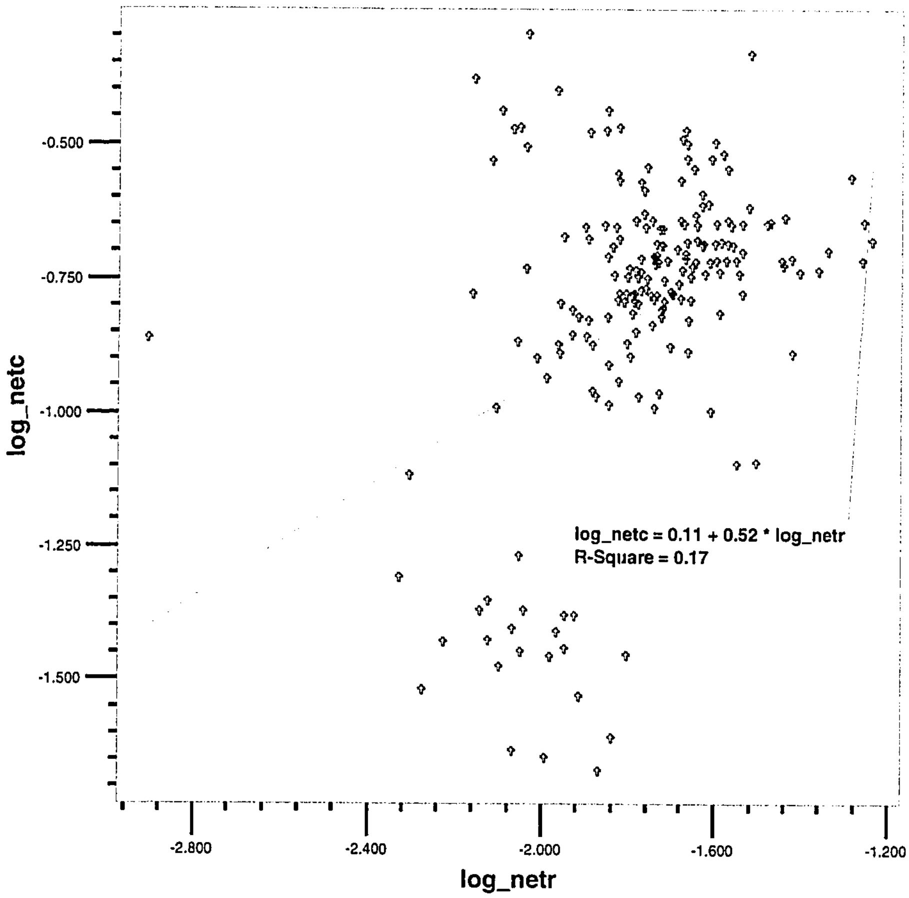
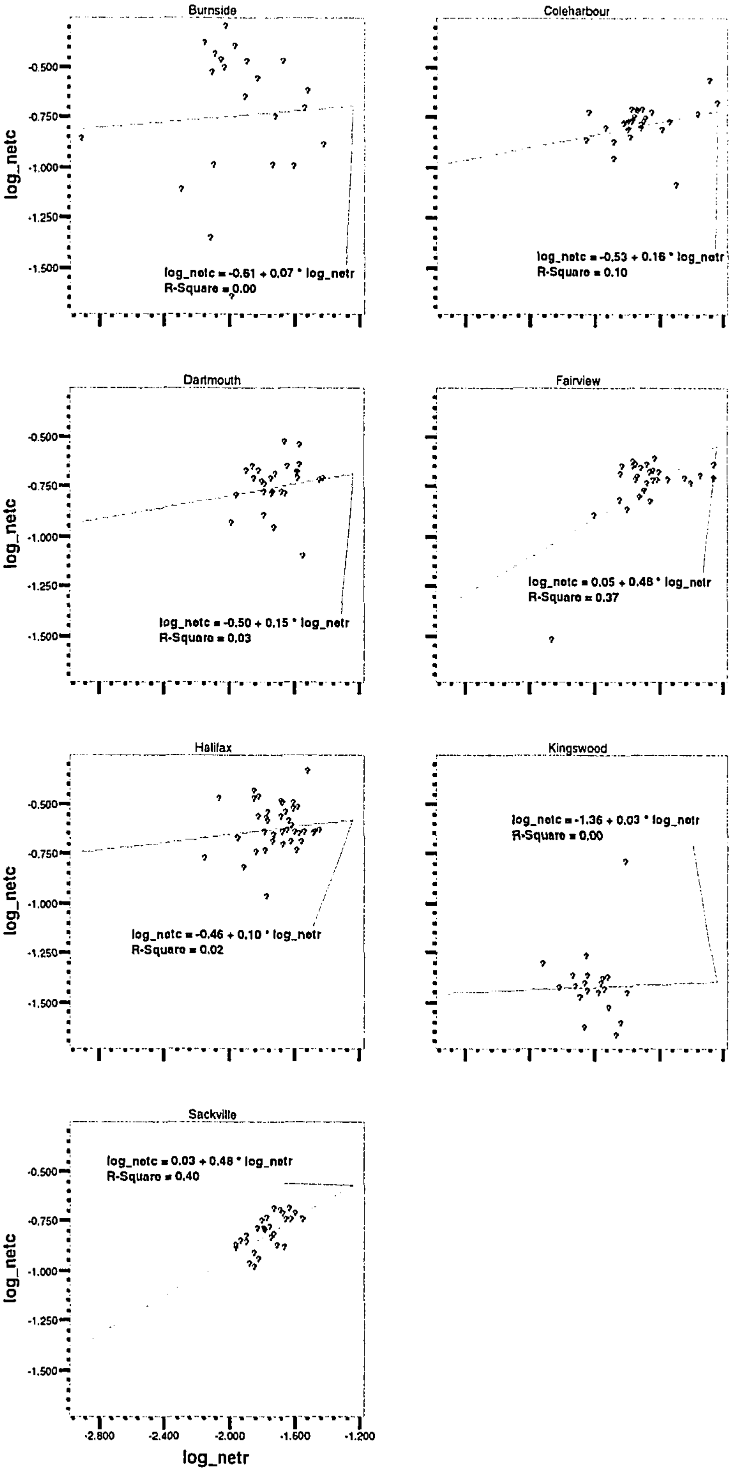


Figure 5-6 Scatter plot graph (200m Circles)



Chapter - 6 Principal component analysis

The purposes of using Factor analysis in the research are three-fold: 1) to remove redundant (highly correlated) measures and replace the entire data file with a smaller number of uncorrelated and generalized factors where possible; 2) to discern underlying structural relationships among measures, which could represent styles of urban development (SPSS Base, 2004); 3) to compare the structure and meaning of components (factors) derived from the two data sets with different circle radii.

There are several extraction methods for constructing a solution in the Factor Analysis procedure. Here, the principal component method was applied with varimax rotation, since this combination explained the most variation in the data, and is widely used. Usually, the initial factor extraction does not supply interpretable factors. Varimax rotation was used to obtain factors that can be named and interpreted. Indeed, varimax is an orthogonal rotation method which simply rotates the axes of the first factor to a variable or group of variables and then rotates the subsequent factors to be at right angles (uncorrelated) with the first (SPSS help, 2005). By this way it lessens the likelihood that the first factor will be a meaningless "general" factor. Compared to the unrotated factor solution, an orthogonal rotation minimizes the number of factors needed to account for the variation of distinct groups of variables (SPSS help, 2005).

In this study, a total of twelve measures was involved as original input variables, and both original and logarithmically transformed data were used in analysis procedures. After comparisons of results, the group of components with better performance was selected for interpretation. Extracted factors were then analyzed and named according to their relationship with measures of urban form. Finally, the component scores were used to compare the different styles of urban development in order to capture dissimilarities in urban development styles among seven different sampling districts using the data sets derived from circles with different radii, and then to compare the outputs from different sampling circle groups for verifying the validity of the conclusions.

It should be noted that after logarithmical transformation, the sampling size was reduced, since the value with zero, which occurred only among three street measures, could not be transformed. However, this would not greatly affect the outcomes of multivariate statistics since the sample size was sufficient for the principal component analysis.

1. Results with 100 meter radius circles

Table 6-1 shows the final results of cumulative percentage after rotation, using original data (non-logarithmic). Only five extracted components had eigenvalues more than 1.0, and these explained 78% of the variability in the original 12 variables. That is, it is possible to considerably reduce the complexity of the data set by using these components, with only a 22% loss of information. However, as shown in Table 6-2, the final cumulative percentage using logarithmically transformed data has a higher value of 85% with only four facters, thus retaining more information with fewer varialbes. Hence, only this group of factors was used for interpretation purposes using the component matrix.

Table 6-1 Variation Explained (using original data) for components with eigenvalues over 1.0

Component	Rotation Sums of Squared Loadings		
	Eigenvalue	% of Variation	Cumulative %
1	2.200	18.334	18.334
2	2.097	17.474	35.809
3	2.003	16.695	52.504
4	1.816	15.137	67.641
5	1.280	10.664	78.305

Table 6-2 Variation Explained (using log-transformed data) for components with eigenvalues over 1.0

Component	Rotation Sums of Squared Loadings		
	Eigenvalue	% of Variation	Cumulative %
1	2.868	23.902	23.902
2	2.651	22.096	45.998
3	2.406	20.049	66.047
4	2.219	18.494	84.541

Table 6-3 Rotated Component Matrix* (using 100m log-transformed data)

		Component (factor)			
Full Name	Variable	1	2	3	4
Mean Proximity	LOG_PROX	**-0.91**	-0.06	0.257	0.025
Net Building Density	LOG_NETD	**0.791**	-0.29	-0.47	0.148
Net Coverage Ratio	LOG_NETC	**0.755**	0.365	0.411	0.124
Median Lot Size	LOG_MEDL	**-0.79**	-0.13	0.363	-0.15
C.V. of Building Size	LOG_BSCO	0.063	**0.891**	0.034	0.001
Mean Shape Index	LOG_MSI	-0.07	**0.73**	0.301	0.087
C.V. of Lot Size	LOG_LSCO	0.208	**0.844**	-0.04	-0.06
Median Building Size	LOG_MEDB	-0.19	0.123	**0.928**	-0.03
Mean Peri/Area Ratio	LOG_MPAR	0.254	-0.04	**-0.93**	0.053
Net Road Density	LOG_NETR	0.222	-0.33	0.008	**0.812**
Net Junction Density	LOG_NETJ	0.096	0.07	-0.04	**0.991**
Junction Frequency	LOG_JUNC	-0.1	0.496	-0.08	**0.708**

Rotation Method: Varimax with Kaiser Normalization.
* - Rotation converged in 5 iterations.

As shown in the rotated component matrix (Table 6-3), the first component is most highly correlated with Log-Prox (- 0.907), and then with Log-NetDen (0.791), Log-NetCR (0.755), and Log-MedLS (- 0.792). This suggests that this factor mainly represents characteristics of "building density" (labelled as F1_B_DEN). High loadings on the second component are apparent for Log-BScov, Log-LScov, and Log-MSI, which are generally related to variation in the size and shape of buildings and lots. This component is called "size variation" (labelled F2_SI_V). The third component is most highly correlated with Log-MedBS and Log-MPAR. This suggests that this factor focuses on the "size of buildings" (labelled F3_B_SI). Inspection of the component scores suggests that the fourth component consists of street measures (Log-NetRD, Log-NetJD, and Log-JuncF), so that is labelled "Street density"

(F4_R_DEN). Finally, the component scores of the first two factors were saved as the input variables for the scatter plot.

Figure 6-1 Scatter graph for all cases on 2 components (100m circles, log-data)

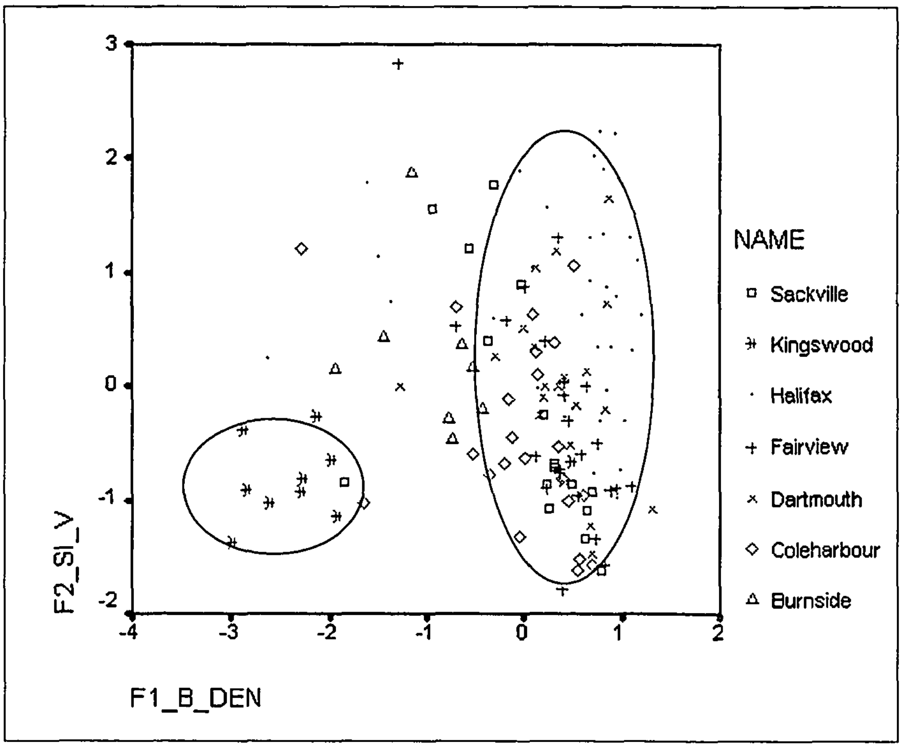


Figure 6-1 shows the scatter plot for all cases (100m radius circle) using the component scores. Only the first two factors were plotted (accounting for 46% variation), since the third factor and fourth factor were of less importance. There were two clouds which can be found in the graph. The main cloud is like an elongated ellipse (shown on the graph), and was located in the right side of the graph, while the minor cloud was situated at the left-bottom corner. For the main cloud, its long axis shows much variation within the data set regarding changes in the area of buildings and lots (more variation on F2_SI_V scores), and short axis indicates only the moderate variation in building density (F1B_DEN). For the minor cloud, most points plotted pertained to Kingswood. These cases had lower scores on components

(F1_B_DEN and F2_ SI_V), implying lower building density but higher homogeneity in the size of buildings and lots.

Figure 6-2 Scatter plot for subgroup centroids (100m circles)

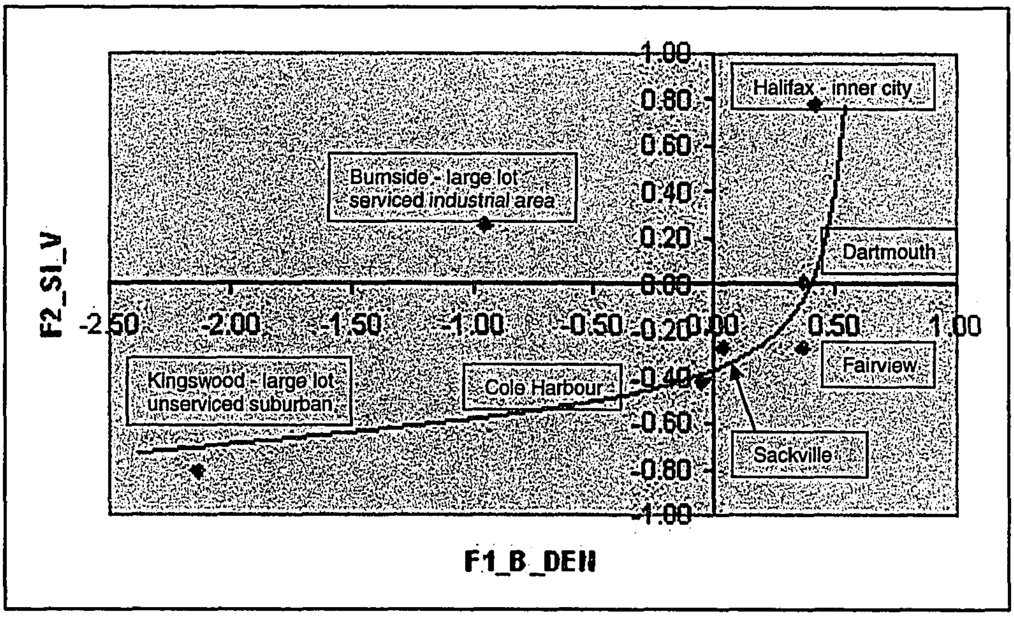


Figure 6-2 presents a simplified scatter plot for group centroids (subgroup mean on both components) using the component scores, which is a way of summarizing the scatter plot. This type of graph is useful for distinguishing relationships between the groups (SPSS Base, 2004). As shown in Figure 6-2, the closeness between each group (different sampling districts) centroid marked with the dot suggests the degree of separation among groups. In turn, closeness reflects similarities or dissimilarities among the groups quantitatively. It is evident that seven centroids can be divided into five groups according to their similarity. Burnside is far from others, which illustrates its unique development style as an industrial area. It has fairly low density and is also fairly heterogeneous. In residential districts, most other groups are close to each other except Kingswood, which represents exurban "large lot" development since 1980s. Kingswood shows greater homogeneity in the size of buildings and lots (low score on

F2_SI_V) and also has the lowest score relating to building density (F1_B_DEN). The centroids of Cole Harbour and Sackville are close together, which reflect layout or form features of newly developed serviced suburban areas. They are homogenous regarding the size of buildings and lots, and have fairly low building densities. The centroids of Dartmouth and Fairview cluster together, suggesting their similarity in styles of older suburban development. Compared with the new suburban areas, they have higher densities and more heterogeneity. Unlike other districts, the Halifax group shows the unique characteristics of inner city development. To be specific, it has the highest building density and is most heterogeneous. These features reflect both its higher land value and its greater variety of land uses and development periods.

As shown in Figure 6-2, a path can be found clearly for several different trends in residential areas. From the centroid of Halifax to the centroid of Kingswood, the time period of development changes from the old to the new, the distance from city center becomes larger and larger, and the building density decreases as well. Overall, the outcomes from this analysis support quantitatively the locations selected for different sampling districts and the hypotheses on styles of urban development.

2. Results with 200 meter radius circles

Comparing the cumulative percentage of variation after rotation achieved derived from two different data sets (shown in Table 6-9 and Table 6-10), the group of components with logarithmically transformed data shows a higher value of 79% than the one using original data. Thus, only this group of factors was interpreted later in the rotated component matrix (Table 6-11). Although this cumulative percentage is lower than the one obtained from circles with 100 meter radius (79% versus 85%), the first two components account for more variation (60% versus 46%).

Table 6-4 Variation Explained (using original data) for components with eigenvalues over 1.0

Component	Rotation Sums of Squared Loadings		
	Eigenvalue	% of Variation	Cumulative %
1	3.437	28.645	28.645
2	2.459	20.493	49.138
3	2.063	17.196	66.333

Table 6-5 Variation Explained (using log-transformed data) for components with eigenvalues over 1.0

Component	Rotation Sums of Squared Loadings		
	Eigenvalue	% of Variation	Cumulative %
1	3.628	30.232	30.232
2	3.599	29.993	60.225
3	2.252	18.765	78.990

Table 6-6 Rotated Component Matrix*

		Component (factor)		
Full Name	Variable	1	2	3
Net Junction Density	LOG_NETJ	**0.908**	-0.190	0.003
Net Road Density	LOG_NETR	**0.809**	-0.184	-0.226
Mean Proximity	LOG_PROX	-0.609	0.624	-0.217
Net Building Density	LOG_NETD	0.602	-0.726	-0.113
Net Coverage Ratio	LOG_NETC	0.763	0.161	0.391
Median Building Size	LOG_MEDB	-0.042	**0.949**	0.078
Mean Peri /Area Ratio	LOG_MPAR	0.055	**-0.948**	-0.021
C.V. of Building Size	LOG_BSCO	0.152	0.049	**0.841**
C.V. of Lot Size	LOG_LSCO	0.073	-0.305	**0.839**
Mean Shape Index	LOG_MSI	-0.021	0.458	0.659
Median Lot Size	LOG_MEDL	-0.595	0.684	-0.258
Junction Frequency	LOG_JUNC	0.666	-0.122	0.264

Rotation Method: Varimax with Kaiser Normalization.
* Rotation converged in 5 iterations

As shown in the rotated component matrix (Table 6-11), the first component is most highly correlated with Log-NetRD (0.809) and Log-NetJD (0.908). This suggests that this factor mainly represents characteristics of "street density" (labelled as F1_R_DEN). High loadings on the second component are apparent from Log-MedBS and Log-MAPR, which are generally related to the "size of buildings" (labelled as F2_B_SI). The third component is most highly correlated with Log-BScov and Log-LScov. This suggests that this factor mainly focuses on variation in the "size variation" (labelled as F3_SI). Then, the component scores of the first two factors were saved as input variables for the scatter plot. Interestingly, though the component ordering of the two data sets from circles with different radii is not the same, the component configurations are very similar, suggesting that contributions of measures are not highly sensitive to the sample size.

Figure 6-3 Scatter graph for all cases on 2 components (200m circles)

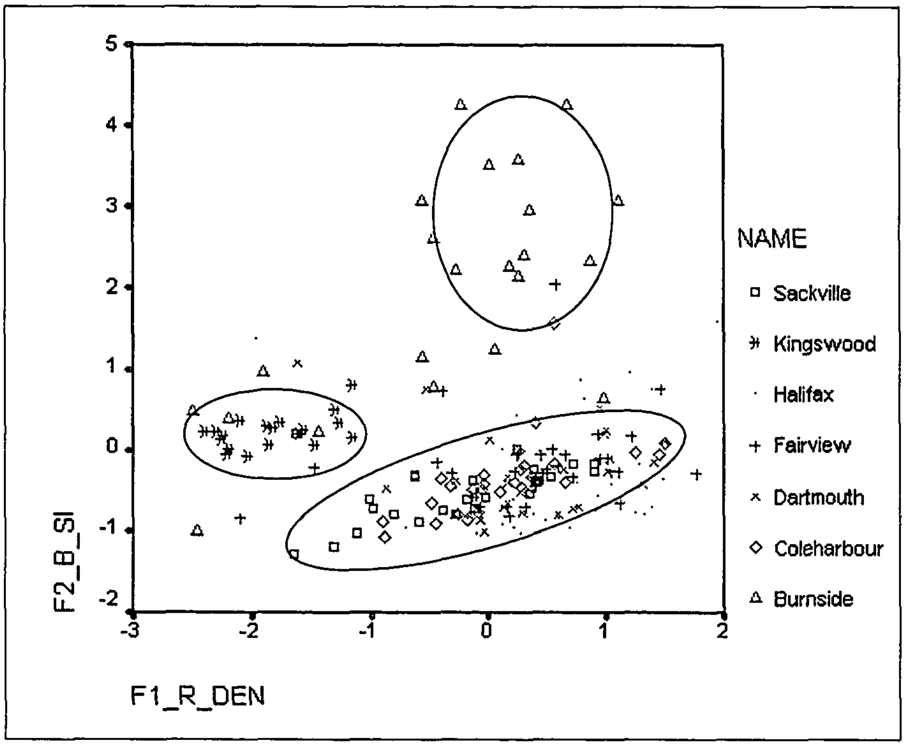


Figure 6-3 shows the scatter plot for all cases (200m radius circle) using the component scores. Only the first two factors were plotted (accounting for 60% variation), since the third factor was considered to be less important. There were three clouds which can be found in the graph (as shown on the graph). The main cloud is like an elongated ellipse (shown on the graph), and was located in the bottom of the graph, while the minor two clouds were situated at the right-top corner and the left middle respectively. For the main cloud, its long axis shows much variation within the data set regarding the street density (F1_R_DEN), and its short axis show slight variation in the building size (F2_B_SI). For the minor cloud in the left middle, most points plotted pertained to Kingswood. These cases had lower scores on street density (F1_B_DEN) but higher scores on building size (F2_ SI_V), suggesting presence of fewer street but larger houses in the area. For another minor cloud, most points plotted pertained to Burnside. Compared with the Kingswood group, these points were not tightly close to each other, implying more heterogeneity. These cases had moderate scores on street density (F1_B_DEN) but higher scores on the building size large (F2_ SI_V), which reflects the presence of large buildings in the area.

Figure 6-4 Scatter plot for subgroup centroids (200m circles)

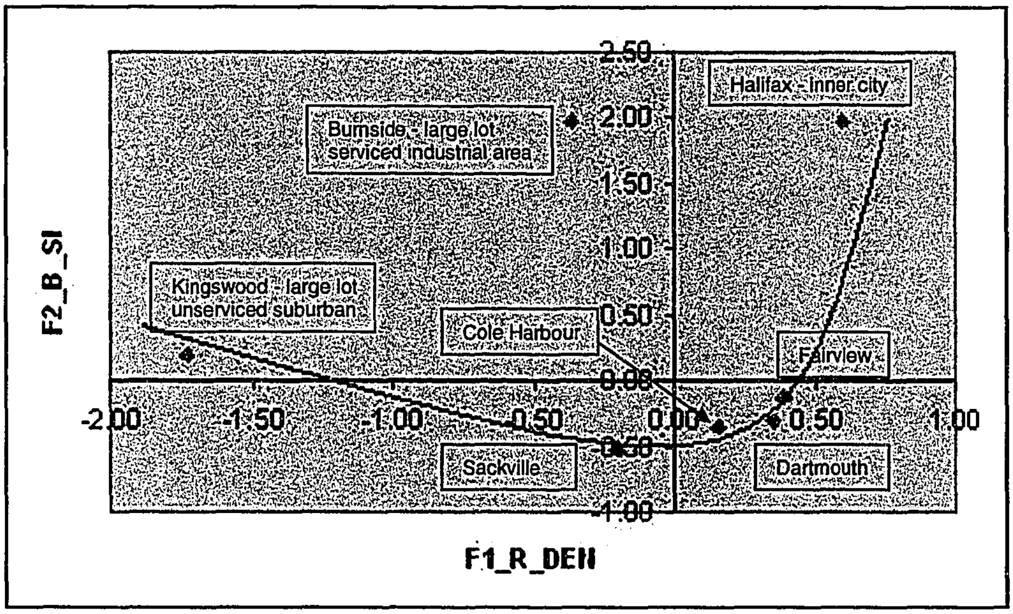


Figure 6-4 presents a simplified scatter plot for group centroids using the component scores. As shown in Figure 6-4, the locations of group centroids are similar to the results obtained from the 100 meter radius dataset in terms of position and closeness to each other, though the composition and configuration of components in the two principal component models are different, particularly for the component 1.

However, overall conclusions for comparing the similarity of different sampling districts are similar. Despite different factor interpretations, the position of districts in factor space is very similar and leads us to similar conclusions. That is, after long-time urbanization, Halifax district has a unique development style as a core area with the highest street density and the largest building size, resulting from a greater mixture of land use. Dartmouth and Fairview (old suburban areas) are similar in urban form, probably owing to large amounts of their development occurring contemporaneously. It is not surprising that Cole Harbour and Sackville (new suburban areas) have similar features of urban development, since the same planning strategies were applied even before the actual construction was carried out, and both are quite homogeneous residential areas. Compared with the old suburban, they have even lower street densities. All four of these suburban districts have lower values on the building size than others, benefiting from the local planning strategies, as expected.

Burnside and Kingswood stand alone from other districts because of their single and particular land uses. Burnside has the largest building size and moderate street density, suggesting its development style for industrial land use. Kingswood has the lowest street density but the building size is larger than the four other suburban residential areas, suggesting a prestige housing development. Since this area was planned as un-serviced or on-site serviced suburban, large lots were required for building their own facilities.

Overall, principal component analysis provided a good model for delineating and interpreting urban development.

Chapter - 7 Conclusions

This research project has been undertaken in an attempt to characterize urban physical form and to reveal historical trends in urban development at the micro level by using urban morphological elements. It has been suggested that, incorporated with detailed and disaggregated data sources for streets, lots, and buildings, GIS sampling techniques are able to provide an effective and efficient way to capture characteristics of urban form quantitatively at any desired geographic scale. In the study area, Halifax Regional Municipality, using a variety of statistical methods, this empirical research attempted to: 1) delineate variability through different urban areas, time periods of development, and land uses using empirical measures; and 2) explore interrelationships and configurations of these measures within different urban areas, land uses, and time periods of development. Some conclusions on the findings will now be presented, followed by a brief discussion of implication for further research.

Most measures used in this study were similar to ones developed by other researchers. However, because of the small sampling unit, about 3 ha and 12 ha respectively (that is, smaller than a 400m x 400m walkable neighborhood, 25 ha sampling unit used by Millward, 50 ha sampling unit used by Song and Knaap, 100 ha sampling unit used by Weston etc.), this research provided more explicit information regarding urban form than provided by previous studies. In addition, unique sampling methods with the computational power of GIS were able to reduce the processing time significantly, which might be quite practical for planners.

The measures employed effectively and efficiently captured different characteristics of urban development, as they vary from place to place, by time-period of development, and by land use. For land use categories, only Single Family Residential (SFR) and industrial land use obtained statistically valid sample sizes (i.e. 30 or more), so results for the other categories are indicative only. In terms of historical trends, land use intensity tended to decline through time; buildings were becoming larger in their footprint area and further apart from each other through time, and they occupied bigger lots than ever before. All three street measures showed decreased road density and decreased junctions along the streets in the study area over time. It should be noted that minor differences are found between the two sets of measure values from the two sizes of sampling circles (that is, 100 meter radius circles and 200 meter radius circles). Sampling circles with 100 meter radius are good for capturing the features of buildings and lots, and sampling circles with 200 meter radius are good for delineating the characteristics of streets. However, overall outcomes from the two data sets are similar.

Allometric (power-law) relationships were tentatively explored among the various measures, on the assumption that site-level design is an integrated system, with inter-relationships between the various aspects, such as proximity, street density, land use intensity etc. The relationships between selected measures are statistically significant, and fairly sensitive to changes in the categorical subgroups. As shown in the scatter diagram, the slope of the log-log regression line (exponent) reflected different dimensionalities of measures and suggested the different rates of change between two measures.

Principal Component Analysis suggests that most data variation can be accounted for by two sets of factors derived from circles with different radii. The most important components were related to measures for size of building and lot, building density, and street density. Using the most important components, the similarity of the seven sampling districts was illustrated and compared. Their similarity and differences related to time periods of development and to land use. In the scatter plots of component scores, Halifax shows typical characteristics of inner city development in that it has highest density and most heterogeneity; Dartmouth and Fairview cluster together, suggesting their similarity in styles of older suburban development; Cole Harbour and Sackville are also close together, which reflects the similarity in urban form between two newly developed serviced suburban areas; Kingswood stands alone from others, since it represents exurban "large lot" unserviced development since the 1980s; Burnside is also far from others, suggesting a recently-developed industrial park. These results confirmed many expectations and results in chapter 4. That is, planning strategies do influence urban form drastically. For example, similar values of several measures such Net Building Density and Net Coverage Ratio can be found between Dartmouth and Fairview, but differences between values for Median Building Size and Median Lot Size may in part reflect differences in planning policies applied.

This research makes a contribution to the study of urban development patterns in the following ways: 1) it offers methods to improve the accuracy and precision of micro-level morphological study on urban form, in that sampling design, sampling unit, and GIS methods used in this study can provide data both effectively and efficiently; 2) it suggests new applications for several micro-level measures of shape and pattern borrowed from landscape ecology, notably mean perimeter-area ratio, mean shape index, and mean building proximity, and 3) it provides detailed empirical assessments of urban patterning which may help high-resolution image classification techniques for land use monitoring in urban area.

This research may also contribute to planning practice, especially in relation to HRM planning strategies, for the following purposes: 1) recommending several key measures which can reflect differences and changes of urban forms; 2) providing necessary empirical data for analysis of metropolitan service costs (for example, the costs study conducted by HRM financial services (2005) could employ results of this study to adjust their estimates of service costs in different residential patterns); 3) measuring urban development patterns in terms of smart growth, in that the measures used are closely related to the main concerns of smart growth. For example, Net Building Density and Net Coverage Ratio and Median Lot Size can reflect compactness of urban form, Net Road Density can reflects can reflect both land use intensity and adequacy of public access, and Net Junction Density and Road Junction Frequency show connectivity and block size inside the sampling unit.

This research project represents an exploratory attempt to quantitatively characterize urban development at the micro level, and brings the power, speed, and precision of GIS software and detailed digital data into formal urban analysis regarding development trends. As far as the author is aware, no similar study has been attempted, and no one has used principal component to interpret micro-level variation in urban form. The most similar study was done by Knaap and Song (2004), but they used an area of 51 ha (one quarter mile circle) as their sampling unit, versus areas of 3.1 ha (100 meter radius circle) and 12.6 ha (200 meter radius circle) in this study. However, owing to limitations of data availability, the lack of empirical guidance, and the magnitude of the research problem, only restricted aspects of urban development trends have been investigated. Therefore, further research approaches can be suggested, as follows:

1) Though measures used in this study are not very sensitive to change in the size of the sampling circle, it is still worthwhile for investigating the sampling strategies, in that the appropriate size of sampling unit is an essential step to attain statistically sound and robust results. For different sampling purposes, it is better to apply different sampling-unit sizes. For example, for morphological research on residential buildings, a sampling circle with a 150m radius would provide good performance, because typically it would contain more than 30 buildings. For street pattern research, circles of 300m radius or quadrats of 500 m x 500 m may be proper rather than other units (Millward, 1975), because units of this size (25 ha) contain a sizeable length of streets, sufficient to analyze street density and pattern.

2) Though measures used in this study might be robust, it is important to understand the nonlinearity that may be inherent in some of these variables. For example, once a residential lot reaches a certain size threshold, the length of connecting sewage lines may increase surprisingly high, which means costs for sewage construction could skyrocket. This relates to the issue of allometry, and the varying dimensionality of the components of urban form.

3) In further research, it is important to make every endeavor to obtain high quality data sources (both archival map and digital map) including built-up time, building bulk etc., which is useful for study of historical development by morphological methods. In addition, using the most recent lot maps and building maps, the land use map can be updated and applied to monitor urban development through time. Combined with pattern reorganization and classification techniques (i.e. Structural analysis and mapping system by Bar and Barnsley, 2004), a lot or building map can be converted to a land use map "automatically".

4) Further research is needed to better understand the relationships between different measures of urban form, which reflect specific aspects of urban development. Since these measures are important for purposes of policy, they deserve additional consideration. The use of other advanced data mining methods will help researchers extract more useful information.

5) The research methods used here can be applied to different study areas in different cities and regions, in order to examine whether or not the measures will be affected by different development styles and development history.

The knowledge obtained from further study will help other researchers and urban planners to better understand development trends in our cities. In turn, a more thorough understanding will help policy makers to draft better-informed policies about our built environment.

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Appendix-1: The results of Mann-Whitney test

Significances (100 meter radius circles)

ProX	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.007	X					
Dartmouth	0.003	0.102	x				
Fairview	0.001	0.128	0.728	x			
Halifax	0.001	0.006	0.124	0.045	x		
Kingswood	0.007	0.000	0.000	0.000	0.000	x	
Sackville	0.017	0.994	0.037	0.141	0.000	0.000	x

NetCR	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.416	X					
Dartmouth	0.564	0.000	x				
Fairview	0.894	0.001	0.859	x			
Halifax	0.130	0.000	0.005	0.006	x		
Kingswood	0.000	0.000	0.000	0.000	0.000	x	
Sackville	0.848	0.442	0.002	0.003	0.000	0.000	x

BSCov	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.089	X					
Dartmouth	0.790	0.025	x				
Fairview	0.477	0.104	0.352	x			
Halifax	0.004	0.000	0.010	0.000	x		
Kingswood	0.000	0.041	0.000	0.000	0.000	x	
Sackville	0.156	0.584	0.046	0.220	0.000	0.008	x

MPAR	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.002	X					
Dartmouth	0.001	0.451	x				
Fairview	0.001	0.391	0.191	x			
Halifax	0.000	0.894	0.861	0.345	x		
Kingswood	0.005	0.004	0.009	0.075	0.013	x	
Sackville	0.001	0.679	0.363	0.416	0.667	0.004	x

LSCov	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.824	X					
Dartmouth	0.026	0.089	x				
Fairview	0.494	0.625	0.280	x			
Halifax	0.000	0.000	0.003	0.001	x		
Kingswood	0.158	0.058	0.000	0.014	0.000	x	
Sackville	0.134	0.141	0.647	0.391	0.010	0.001	x

NetJD	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.002	X					

Dartmouth	0.004	0.671	x				
Fairview	0.000	0.275	0.444	x			
Halifax	0.000	0.176	0.398	0.966	x		
Kingswood	0.916	0.000	0.000	0.000	0.000	x	
Sackville	0.191	0.034	0.033	0.003	0.001	0.150	x

NetDen	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	X					
Dartmouth	0.000	0.315	x				
Fairview	0.000	0.767	0.584	x			
Halifax	0.000	0.603	0.875	0.663	x		
Kingswood	0.243	0.000	0.000	0.000	0.000	x	
Sackville	0.000	0.859	0.193	0.929	0.424	0.000	x

MedBS	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	X					
Dartmouth	0.005	0.535	x				
Fairview	0.009	0.011	0.101	x			
Halifax	0.007	0.121	0.383	0.333	x		
Kingswood	0.015	0.002	0.038	0.469	0.168	x	
Sackville	0.002	0.095	0.723	0.033	0.521	0.019	x

MSI	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	X					
Dartmouth	0.035	0.000	x				
Fairview	0.002	0.023	0.072	x			
Halifax	0.966	0.000	0.001	0.000	x		
Kingswood	0.000	0.438	0.001	0.139	0.000	x	
Sackville	0.000	0.728	0.002	0.088	0.000	0.773	x

MedLS	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	X					
Dartmouth	0.000	0.965	x				
Fairview	0.000	0.214	0.121	x			
Halifax	0.000	0.061	0.006	0.000	x		
Kingswood	0.836	0.000	0.000	0.000	0.000	x	
Sackville	0.000	0.284	0.152	0.813	0.001	0.000	x

NetRD	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.025	X					
Dartmouth	0.002	0.375	x				
Fairview	0.004	0.379	0.813	x			
Halifax	0.003	0.475	0.646	0.681	x		
Kingswood	0.625	0.002	0.000	0.000	0.000	x	
Sackville	0.027	0.352	0.037	0.058	0.061	0.004	x

JuncF	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville

Burnside	x						
ColeHarbour	0.001	X					
Dartmouth	0.002	0.710	x				
Fairview	0.000	0.415	0.760	x			
Halifax	0.000	0.069	0.226	0.294	x		
Kingswood	0.972	0.000	0.001	0.000	0.000	x	
Sackville	0.180	0.042	0.043	0.009	0.000	0.150	x

Significances (100 meter radius circles)

ProX	1900	1925	1950	1970	1985
1900	x				
1925	0.477	x			
1950	0.078	0.478	x		
1970	0.000	0.084	0.175	x	
1985	0.000	0.010	0.006	0.003	x

NetCR	1900	1925	1950	1970	1985
1900	x				
1925	0.016	x			
1950	0.000	0.591	x		
1970	0.000	0.561	0.582	x	
1985	0.000	0.023	0.002	0.000	x

BSCov	1900	1925	1950	1970	1985
1900	x				
1925	0.189	x			
1950	0.048	0.813	x		
1970	0.000	0.039	0.021	x	
1985	0.000	0.007	0.001	0.063	x

MPAR	1900	1925	1950	1970	1985
1900	x				
1925	0.365	x			
1950	0.058	0.451	x		
1970	0.518	0.223	0.002	x	
1985	0.021	0.021	0.000	0.002	x

LSCov	1900	1925	1950	1970	1985
1900	x				
1925	0.915	x			
1950	0.007	0.033	x		
1970	0.000	0.001	0.044	x	
1985	0.000	0.000	0.010	0.232	x

NetJD	1900	1925	1950	1970	1985
1900	x				
1925	0.028	x			
1950	0.074	0.226	x		
1970	0.015	0.507	0.482	x	
1985	0.000	0.072	0.001	0.000	x

NetDen	1900	1925	1950	1970	1985
1900	x				
1925	0.859	x			
1950	0.406	0.312	x		
1970	0.564	0.694	0.265	x	
1985	0.000	0.013	0.000	0.000	x

MedBS	1900	1925	1950	1970	1985
1900	x				
1925	0.546	x			
1950	0.040	0.451	x		
1970	0.844	0.442	0.011	x	
1985	0.449	0.123	0.004	0.219	x

MSI	1900	1925	1950	1970	1985
1900	x				
1925	0.522	x			
1950	0.029	0.155	x		
1970	0.000	0.001	0.000	x	
1985	0.000	0.020	0.030	0.192	x

MedLS	1900	1925	1950	1970	1985
1900	x				
1925	0.118	x			
1950	0.004	0.621	x		
1970	0.000	0.056	0.002	x	
1985	0.000	0.009	0.000	0.002	x

NetRD	1900	1925	1950	1970	1985
1900	x				
1925	0.016	x			
1950	0.922	0.021	x		
1970	0.368	0.049	0.383	x	
1985	0.001	0.644	0.001	0.001	x

JuncF	1900	1925	1950	1970	1985
1900	x				
1925	0.135	x			
1950	0.013	0.666	x		
1970	0.001	0.471	0.645	x	
1985	0.000	0.030	0.003	0.001	x

Significances (100 meter radius circles)

* SFR - Single Family Residential

** MFR - Multiple Family Residential

ProX	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.174	x				
Industrial	0.185	0.871	x			
MixedLanduse	0.186	0.007	0.008	x		
SFR	0.600	0.075	0.020	0.438	x	
MFR	0.852	0.187	0.088	0.362	0.910	x

NetCR	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.082	x				
3	0.041	0.645	x			
4	0.045	0.703	0.756	x		
5	0.000	0.184	0.077	0.014	x	
6	0.055	0.947	1.000	0.737	0.153	x

BSCov	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.415	x				
3	0.000	0.000	x			
4	0.200	0.866	0.000	x		
5	0.000	0.000	0.001	0.000	x	
6	0.026	0.099	0.563	0.103	0.165	x

MPRA	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.870	x				
3	0.078	0.123	x			
4	0.006	0.008	0.001	x		
5	0.002	0.003	0.000	0.622	x	
6	0.420	0.410	0.524	0.002	0.001	x

LSCov	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.446	x				
3	0.000	0.000	x			
4	0.317	0.672	0.000	x		
5	0.000	0.001	0.641	0.000	x	
6	0.756	0.408	0.104	0.230	0.399	x

NetJD	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.054	x				
3	0.003	0.162	x			
4	0.457	0.050	0.003	x		
5	0.026	0.341	0.002	0.145	x	
6	0.268	0.785	0.227	0.396	0.990	x

NetDen	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.157	x				
3	0.007	0.386	x			
4	0.002	0.000	0.000	x		
5	0.002	0.000	0.000	0.692	x	
6	0.137	0.895	0.163	0.000	0.001	x

MedBS	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.624	x				

3	0.194	0.304	x			
4	0.041	0.002	0.001	x		
5	0.042	0.001	0.000	0.230	x	
6	0.292	0.553	0.761	0.014	0.006	x

MSI	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.301	x				
3	0.177	0.705	x			
4	0.001	0.065	0.052	x		
5	0.000	0.000	0.000	0.000	x	
6	0.852	0.429	0.236	0.003	0.000	x

MedLS	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.384	x				
3	0.002	0.040	x			
4	0.215	0.042	0.000	x		
5	0.600	0.625	0.000	0.001	x	
6	0.457	0.947	0.288	0.068	0.374	x

NetRD	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.142	x				
3	0.035	0.135	x			
4	0.749	0.083	0.013	x		
5	0.779	0.132	0.003	0.812	x	
6	0.457	0.429	0.179	0.415	0.512	x

JuncF	1.000	2.000	3.000	4.000	5.000	6.000
1	x					
2	0.054	x				
3	0.001	0.065	x			
4	0.269	0.115	0.000	x		
5	0.005	0.914	0.003	0.013	x	
6	0.194	0.838	0.138	0.513	0.726	x

Significances (200 meter radius circles)

ProX	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	x					
Dartmouth	0.000	0.198	x				
Fairview	0.000	0.824	0.322	x			
Halifax	0.000	0.000	0.001	0.000	x		
Kingswood	0.008	0.000	0.000	0.000	0.000	x	
Sackville	0.000	0.535	0.416	0.848	0.000	0.000	x

BSCov	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.055	x					
Dartmouth	0.574	0.174	x				
Fairview	0.147	0.249	0.790	x			

Halifax	0.018	0.001	0.011	0.003	x		
Kingswood	0.000	0.000	0.000	0.000	0.000	x	
Sackville	0.046	0.690	0.104	0.124	0.001	0.005	x

MPAR	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	x					
Dartmouth	0.000	0.143	x				
Fairview	0.000	0.460	0.179	x			
Halifax	0.000	0.006	0.439	0.024	x		
Kingswood	0.000	0.000	0.002	0.044	0.000	x	
Sackville	0.000	0.802	0.344	0.231	0.040	0.000	x

LSCov	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.579	x					
Dartmouth	0.023	0.483	x				
Fairview	0.010	0.540	0.947	x			
Halifax	0.000	0.002	0.009	0.005	x		
Kingswood	0.000	0.000	0.000	0.000	0.000	x	
Sackville	0.061	0.223	0.762	0.641	0.054	0.000	x

NetJD	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	x					
Dartmouth	0.000	0.198	x				
Fairview	0.000	0.048	0.734	x			
Halifax	0.000	0.000	0.059	0.153	x		
Kingswood	0.134	0.000	0.000	0.000	0.000	x	
Sackville	0.014	0.101	0.009	0.001	0.000	0.000	x

MedBS	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	x					
Dartmouth	0.000	0.496	x				
Fairview	0.000	0.139	0.204	x			
Halifax	0.000	0.255	0.762	0.068	x		
Kingswood	0.000	0.000	0.001	0.017	0.000	x	
Sackville	0.000	0.506	0.515	0.071	0.298	0.000	x

MSI	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	x					
Dartmouth	0.001	0.000	x				
Fairview	0.000	0.000	0.941	x			
Halifax	0.735	0.000	0.000	0.000	x		
Kingswood	0.000	0.002	0.005	0.005	0.000	x	
Sackville	0.000	0.790	0.000	0.000	0.000	0.046	x

MedLS	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	x					

Dartmouth	0.000	0.391	x				
Fairview	0.000	1.000	0.179	x			
Halifax	0.000	0.000	0.000	0.000	x		
Kingswood	0.745	0.000	0.000	0.000	0.000	x	
Sackville	0.000	0.589	0.214	0.824	0.000	0.000	x

NetRD	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.000	x					
Dartmouth	0.000	0.918	x				
Fairview	0.000	0.367	0.408	x			
Halifax	0.000	0.431	0.424	0.961	x		
Kingswood	0.329	0.000	0.000	0.000	0.000	x	
Sackville	0.000	0.183	0.214	0.043	0.025	0.000	x

JuncF	Burnside	ColeHarbour	Dartmouth	Fairview	Halifax	Kingswood	Sackville
Burnside	x						
ColeHarbour	0.046	x					
Dartmouth	0.001	0.025	x				
Fairview	0.001	0.037	0.605	x			
Halifax	0.000	0.000	0.056	0.005	x		
Kingswood	0.070	0.000	0.000	0.000	0.000	x	
Sackville	0.486	0.062	0.001	0.001	0.000	0.001	x

Significances (200 meter radius circles)

ProX	1900	1925	1950	1970	1985
1900	x				
1925	0.696	x			
1950	0.042	0.220	x		
1970	0.000	0.030	0.107	x	
1985	0.000	0.000	0.000	0.000	x

BSCov	1900	1925	1950	1970	1985
1900	x				
1925	0.887	x			
1950	0.045	0.149	x		
1970	0.000	0.005	0.024	x	
1985	0.000	0.004	0.030	0.952	x

MPAR	1900	1925	1950	1970	1985
1900	x				
1925	0.082	x			
1950	0.014	0.451	x		
1970	0.099	0.003	0.000	x	
1985	0.000	0.000	0.000	0.001	x

LSCov	1900	1925	1950	1970	1985
1900	x				
1925	0.434	x			
1950	0.002	0.004	x		
1970	0.000	0.000	0.207	x	

1985	0.000	0.000	0.060	0.397	x

NetJD	1900	1925	1950	1970	1985
1900	x				
1925	0.271	x			
1950	0.883	0.312	x		
1970	0.015	0.293	0.033	x	
1985	0.000	0.000	0.000	0.000	x

MedBS	1900	1925	1950	1970	1985
1900	x				
1925	0.025	x			
1950	0.010	0.883	x		
1970	0.393	0.002	0.000	x	
1985	0.006	0.000	0.000	0.001	x

MSI	1900	1925	1950	1970	1985
1900	x				
1925	0.256	x			
1950	0.018	0.127	x		
1970	0.000	0.001	0.000	x	
1985	0.000	0.018	0.042	0.111	x

MedLS	1900	1925	1950	1970	1985
1900	x				
1925	0.394	x			
1950	0.002	0.033	x		
1970	0.000	0.000	0.000	x	
1985	0.000	0.000	0.000	0.000	x

NetRD	1900	1925	1950	1970	1985
1900	x				
1925	0.271	x			
1950	0.203	0.010	x		
1970	0.908	0.177	0.116	x	
1985	0.000	0.030	0.000	0.000	x

JuncF	1900	1925	1950	1970	1985
1900	x				
1925	0.722	x			
1950	0.203	0.478	x		
1970	0.000	0.008	0.022	x	
1985	0.000	0.000	0.000	0.000	x

Significances (200 meter radius circles)

* SFR - Single Family Residential

** MFR - Multiple Family Residential

ProX	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.292	x				
Industrial	0.000	0.014	x			

MixedLanduse	0.908	0.212	0.000	x		
SFR	0.720	0.412	0.000	0.860	x	
MFR	0.275	1.000	0.000	0.098	0.204	x

BSCov	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.405	x				
Industrial	0.000	0.001	x			
MixedLanduse	0.624	0.326	0.000	x		
SFR	0.000	0.000	0.000	0.000	x	
MFR	0.005	0.006	0.865	0.012	0.016	x

MPAR	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.739	x				
Industrial	0.016	0.006	x			
MixedLanduse	0.003	0.031	0.000	x		
SFR	0.001	0.028	0.000	0.501	x	
MFR	0.459	0.329	0.087	0.003	0.002	x

LSCov	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.598	x				
Industrial	0.000	0.005	x			
MixedLanduse	0.470	0.821	0.000	x		
SFR	0.002	0.010	0.480	0.000	x	
MFR	0.972	0.558	0.006	0.450	0.023	x

NetJD	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.183	x				
Industrial	0.015	0.106	x			
MixedLanduse	0.453	0.121	0.000	x		
SFR	0.398	0.372	0.000	0.458	x	
MFR	0.305	0.770	0.556	0.186	0.326	x

MedBS	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.782	x				
Industrial	0.001	0.001	x			
MixedLanduse	0.046	0.007	0.000	x		
SFR	0.069	0.013	0.000	0.212	x	
MFR	0.307	0.329	0.030	0.006	0.005	x

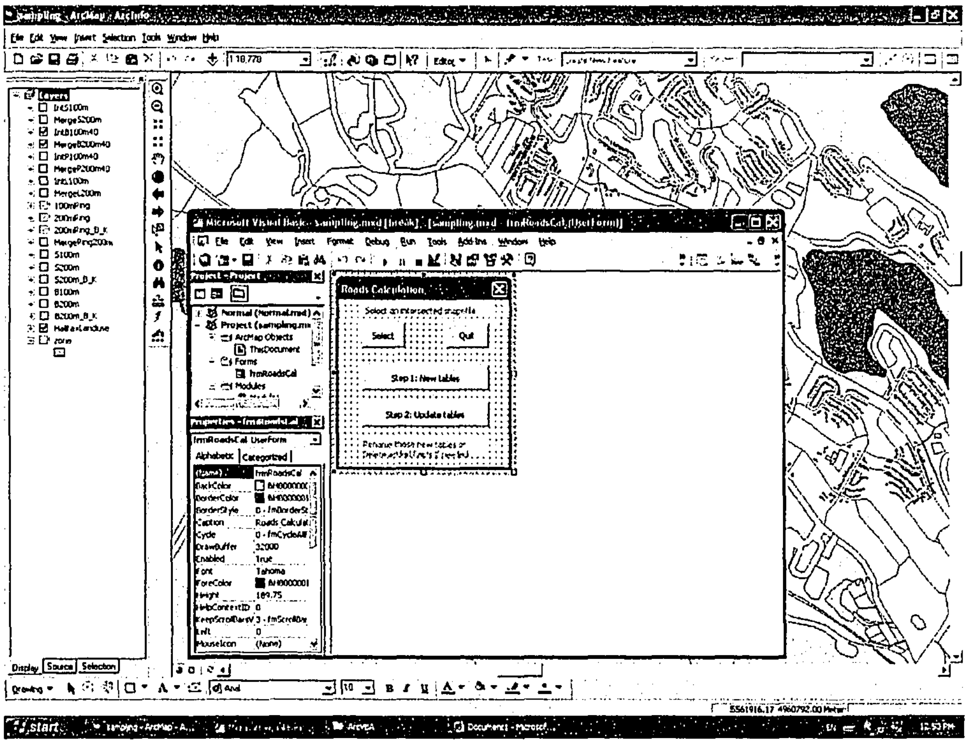
MSI	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.134	x				
Industrial	0.504	0.010	x			
MixedLanduse	0.001	0.000	0.000	x		
SFR	0.000	0.000	0.000	0.001	x	
MFR	0.275	0.922	0.110	0.005	0.000	x

MedLS	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.405	x				
Industrial	0.000	0.013	x			
MixedLanduse	0.273	0.650	0.000	x		
SFR	0.014	0.811	0.000	0.086	x	
MFR	0.245	0.770	0.000	0.238	0.743	x

NetRD	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.108	x				
Industrial	0.006	0.485	x			
MixedLanduse	0.544	0.054	0.001	x		
SFR	0.759	0.036	0.000	0.209	x	
MFR	0.805	0.380	0.118	0.962	0.544	x

JuncF	Commercial	Goverment	Industrial	MixedLanduse	SFR	MFR
Commercial	x					
Government	0.437	x				
Industrial	0.039	0.106	x			
MixedLanduse	0.470	0.521	0.002	x		
SFR	0.114	0.599	0.039	0.023	x	
MFR	0.273	0.494	0.805	0.108	0.386	x

Appendix-2: The VBA script for RoadCal



***The functions of this tool:

* Update the lengths of polylines.

* Create the blank table and insert cell values.

* Find X/Y values of frompoint and topoint.

* Export the total length of segments, and the number of junctions, segments etc.

****
***

```
--------------------------------------------------Roadcal-1
Option Explicit
Public pFClass As IFeatureClass
Public ptable As esriCore.ITable
Public ptable2 As esriCore.ITable

Private Sub CmdQuit_Click()
Unload Me
End Sub

Private Sub CmdBrowse_Click()
   'Set up browser
    Dim pBrowser As IGxDialog
    Set pBrowser = New GxDialog

    pBrowser.Title = "Select Featureclass"
    pBrowser.ButtonCaption = "Select"
    pBrowser.AllowMultiSelect = False
    pBrowser.StartingLocation = "c:\Gabriel"

    'Open only polyline files
```

```
    Dim pGxFilter As IGxObjectFilter
    Set pGxFilter = New GxFilterPolylineFeatureClasses
    Set pBrowser.ObjectFilter = pGxFilter

    Dim pEnumGX As IEnumGxObject
    pBrowser.DoModalOpen 0, pEnumGX

    Dim pPolylineFile As IGxObject
    Set pPolylineFile = pEnumGX.Next

    If pPolylineFile Is Nothing Then
    Exit Sub
    End If
    MsgBox "Confirm the file name :" & pPolylineFile.Name

    'Export the selected file from ArcCatalog to ArcMap
    Dim pGxdataset As IGxDataset
    Set pGxdataset = pPolylineFile

    Dim pDataset As IDataset
    Set pDataset = pGxdataset.Dataset

    Set pFClass = pDataset

End Sub

Private Sub CmdStep1_Click()
On Error GoTo EH

    Dim pDataset2 As IDataset
    Set pDataset2 = pFClass
    Dim pFWS As esriCore.IFeatureWorkspace
    Set pFWS = pDataset2.Workspace

   'create the tables
    Set ptable = createObjectClass(pFWS, "XYvalue")
    Set ptable2 = createObjectClass(pFWS, "RoadPattern")

''add the fields for XYvalue table
    Dim pField As IField
    Set pField = New Field
    Dim pFieldEdit As IFieldEdit
    Set pFieldEdit = pField

    pFieldEdit.Name = "RingIDs"
    pFieldEdit.Type = esriFieldTypeInteger
    ptable.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "Xvalue"
    pFieldEdit.Type = esriFieldTypeDouble
    ptable.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "Yvalue"
    pFieldEdit.Type = esriFieldTypeDouble
    ptable.AddField pField

''add the fields for RoadPattern table
    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "RingIDNo"
    pFieldEdit.Type = esriFieldTypeInteger
    ptable2.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "TtlLength"
    pFieldEdit.Type = esriFieldTypeDouble
    ptable2.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "TtlJuncs"
    pFieldEdit.Type = esriFieldTypeInteger
    ptable2.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "TtlSgmts"
    pFieldEdit.Type = esriFieldTypeInteger
    ptable2.AddField pField
EH:
Exit Sub
End Sub
```

```
Private Sub CmdStep2_Click()

'Update the segment length and X/Y value for the intersected shapefile
   'Add the blank field
    Dim pField As IField
    Set pField = New Field
    Dim pFieldEdit As IFieldEdit
    Set pFieldEdit = New Field

    pFieldEdit.Name = "Length"
    pFieldEdit.Type = esriFieldTypeDouble
    pFClass.AddField pFieldEdit

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "FromX"
    pFieldEdit.Type = esriFieldTypeDouble
    pFClass.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "FromY"
    pFieldEdit.Type = esriFieldTypeDouble
    pFClass.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "ToX"
    pFieldEdit.Type = esriFieldTypeDouble
    pFClass.AddField pField

    Set pField = New Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "ToY"
    pFieldEdit.Type = esriFieldTypeDouble
    pFClass.AddField pField

   'Count the field index
    Dim pFields As IFields
    Set pFields = pFClass.Fields

    Dim intRingIDval As Integer
    intRingIDval = pFields.FindField("RingID")
    Dim intLengthVal As Integer
    intLengthVal = pFields.FindField("Length")
    Dim intFromXval As Integer
    intFromXval = pFields.FindField("FromX")
    Dim intFromYval As Integer
    intFromYval = pFields.FindField("FromY")
    Dim intToXval As Integer
    intToXval = pFields.FindField("ToX")
    Dim intToYval As Integer
    intToYval = pFields.FindField("ToY")


   ' Add the value for each cell
    Dim pFCursor As IFeatureCursor
    Set pFCursor = pFClass.Update(Nothing, True)

    Dim pFeature As IFeature
    Set pFeature = pFCursor.NextFeature
       'Update the length of all segments
        Do Until pFeature Is Nothing
           Dim dblLength As Double
           Dim pCurve As ICurve
           Set pCurve = pFeature.Shape
           dblLength = pCurve.Length

           pFeature.Value(intLengthVal) = dblLength

           pFCursor.UpdateFeature pFeature
           Set pFeature = pFCursor.NextFeature
        Loop
        Set pFCursor = Nothing

       'Get X/Y values and add to cells
        Set pFCursor = pFClass.Update(Nothing, True)
        Set pFeature = pFCursor.NextFeature

        Do Until pFeature Is Nothing
           Dim pGeom As IGeometry
           Set pGeom = pFeature.Shape

           Dim pPolyline As IPolyline
           Set pPolyline = pGeom
```

```
            Dim pfromP As IPoint
            Set pfromP = pPolyline.FromPoint
            Dim ptoP As IPoint
            Set ptoP = pPolyline.ToPoint

            pFeature.Value(intFromXval) = pfromP.X
            pFeature.Value(intFromYval) = pfromP.Y
            pFeature.Value(intToXval) = ptoP.X
            pFeature.Value(intToYval) = ptoP.Y

            pFCursor.UpdateFeature pFeature
            Set pFeature = pFCursor.NextFeature
        Loop
        Set pFCursor = Nothing

''Add values for the XYvalue table
   'Get and add the RingIDs and XY values
    Dim pDataset3 As IDataset
    Set pDataset3 = pFClass
    Dim pFWS2 As esriCore.IFeatureWorkspace
    Set pFWS2 = pDataset3.Workspace
    Set ptable = pFWS2.OpenTable("XYvalue")

    Set pFields = ptable.Fields
    Dim inRingIDs As Integer
    inRingIDs = pFields.FindField("RingIDs")
    Dim inXval As Integer
    inXval = pFields.FindField("Xvalue")
    Dim inYval As Integer
    inYval = pFields.FindField("Yvalue")

    'insert RingIDs and FromPoint XY values
    Set pFCursor = pFClass.Search(Nothing, True)
    Set pFeature = pFCursor.NextFeature

    Dim pTCursor As ICursor
    Set pTCursor = ptable.Insert(True)
    Dim pRBuffer As IRowBuffer
    Set pRBuffer = ptable.CreateRowBuffer
       Do Until pFeature Is Nothing
          pRBuffer.Value(1) = pFeature.Value(intRingIDval)
          pRBuffer.Value(2) = pFeature.Value(intRingIDval)
          pRBuffer.Value(3) = pFeature.Value(intFromXval)
          pRBuffer.Value(4) = pFeature.Value(intFromYval)

          pTCursor.InsertRow pRBuffer
          Set pFeature = pFCursor.NextFeature
       Loop
    Set pFCursor = Nothing
    Set pTCursor = Nothing

    'insert RingIDs and ToPoint XY values
    Set pFCursor = pFClass.Search(Nothing, True)
    Set pFeature = pFCursor.NextFeature

    Set pTCursor = ptable.Insert(True)
    Set pRBuffer = ptable.CreateRowBuffer
       Do Until pFeature Is Nothing
          pRBuffer.Value(1) = pFeature.Value(intRingIDval)
          pRBuffer.Value(2) = pFeature.Value(intRingIDval)
          pRBuffer.Value(3) = pFeature.Value(intToXval)
          pRBuffer.Value(4) = pFeature.Value(intToYval)

          pTCursor.InsertRow pRBuffer
          Set pFeature = pFCursor.NextFeature
       Loop
    Set pFCursor = Nothing
    Set pTCursor = Nothing

'**** Make a copy of XYvalue
    Dim ptable3 As ITable
    Set pDataset3 = ptable
    Set ptable3 = pDataset3.Copy("XYvalue_copy", pFWS2)
    Set ptable3 = Nothing
    Set pDataset3 = Nothing
    Set ptable = Nothing
'****
'''Add the cell value to RoadPattern table
    Set ptable2 = pFWS2.OpenTable("RoadPattern")

    'looking for the Maximum RingID
    Dim i, Ridmin, RidMax As Integer
    Ridmin = InputBox("Enter the minimum RingID")
    RidMax = 0
    Set pFCursor = pFClass.Search(Nothing, True)
    Set pFeature = pFCursor.NextFeature
    'RidMin = 99999 (another method)
```

```
      Do Until pFeature Is Nothing
         If RidMax <= pFeature.Value(intRingIDval) Then
         RidMax = pFeature.Value(intRingIDval)
         End If
         'If RidMin > pFeature.Value(intRingIDval) Then
         'RidMin = pFeature.Value(intRingIDval)
         'End If
         Set pFeature = pFCursor.NextFeature
      Loop
   Set pFCursor = Nothing

   'insert cell values
   Set pTCursor = ptable2.Insert(True)
   Set pRBuffer = ptable2.CreateRowBuffer

   For i = Ridmin To RidMax Step 1
     'get segment #
      Dim pFilter As IQueryFilter
      Set pFilter = New QueryFilter
      pFilter.WhereClause = "RingID = " & i
      Dim Sgmts As Integer
      Sgmts = pFClass.FeatureCount(pFilter)

     'get total length
      Set pFCursor = pFClass.Search(pFilter, False)
      Set pFeature = pFCursor.NextFeature
      Dim TL As Double
      TL = 0
         Do Until pFeature Is Nothing
            If pFeature.Value(intRingIDval) = i Then
            TL = TL + pFeature.Value(intLengthVal)
            End If
         Set pFeature = pFCursor.NextFeature
         Loop
      Set pFCursor = Nothing
      Set pFilter = Nothing

     'get junctions
      Set ptable = pFWS2.OpenTable("XYvalue")
      Dim X, Y As Double
      Dim Juncs, TempC As Integer
      Juncs = 0
      TempC = 0

         'ascending the XY value table
'          Dim pTableSort As ITableSort
'          Set pTableSort = New esriCore.TableSort
'          With pTableSort
'               .Fields = "RingIDs"
'               .Ascending("RingIDs") = True
'          Set .Table = ptable
'          End With
'          pTableSort.Sort Nothing
'          Set pTCursor2 = pTableSort.Rows

      Set pFilter = New QueryFilter
      pFilter.WhereClause = "RingIDs = " & i
      Dim pTCursor2 As ICursor
      Set pTCursor2 = ptable.Search(pFilter, False)
      Dim pRow2 As IRow
      Set pRow2 = pTCursor2.NextRow
         Do While Not pRow2 Is Nothing
         X = pRow2.Value(inXval)
         Y = pRow2.Value(inYval)
         Set pFilter = New QueryFilter
         pFilter.WhereClause = "RingIDs = " & i & "And Xvalue = " & X & "And Yvalue =
     " & Y

         TempC = ptable.RowCount(pFilter)
         If TempC >= 3 Then
         Juncs = Juncs + 1
         End If
         ptable.DeleteSearchedRows pFilter
'        Set pFilter = Nothing
'        Set pTCursor2 = Nothing
'        Set pTCursor2 = ptable.Search(Nothing, False)

         Set pRow2 = pTCursor2.NextRow
         Loop


   pRBuffer.Value(1) = i + 1
   pRBuffer.Value(2) = i
   pRBuffer.Value(3) = TL
   pRBuffer.Value(4) = Juncs
   pRBuffer.Value(5) = Sgmts
```

```
    pTCursor.InsertRow pRBuffer
    Next
    Set pTCursor = Nothing

MsgBox "DONE!!!", vbInformation

End Sub

Private Sub UserForm_Click()

End Sub
-------------------------------------------------------------------RoadCal-2
Option Explicit

'*** create a table inside a dataset ***
Public Function createObjectClass(pFWS As esriCore.IFeatureWorkspace, _
                                  strName As String, _
                                  Optional    pFields    As    esriCore.IFields)    As
        esriCore.IObjectClass

On Error GoTo EH
If pFWS Is Nothing Then Exit Function

' if a fields collection is not passed in then supply our own
 If (pFields Is Nothing) Or IsMissing(pFields) Then
     ' create the fields used by our object
    Set pFields = New esriCore.Fields
    Dim pFieldsEdit As esriCore.IFieldsEdit
    Set pFieldsEdit = pFields
    Dim pFieldEdit As esriCore.IFieldEdit
    pFieldsEdit.FieldCount = 1

    '' create the Item # field
    Dim pField As esriCore.IField
    Set pField = New esriCore.Field
    Set pFieldEdit = pField
    pFieldEdit.Name = "ItemNo"
    pFieldEdit.Type = esriFieldTypeInteger
    pFieldEdit.IsNullable = False
    Set pFieldsEdit.Field(0) = pField
  End If

  Set createObjectClass = pFWS.CreateTable(strName, pFields, Nothing, Nothing, "")

  Exit Function
EH:
    MsgBox Err.Description, vbInformation, "createDatasetFeatureClass"
End Function
```