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THE UNIVERSITY OF ALBERTA

Three Dimensional Mapping as a Tool for the Management of Spatial Information

by

David J. Buckley

A THESIS

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(SIGNED) David J. Buckley

PERMANENT ADDRESS:

702 - 9929 - 113 St

Edmonton, Alberta

T5K 2N9

DATED 14 October 1987

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Three Dimensional Mapping as a Tool for the Management of Spatial Information submitted by David J. Buckley in partial fulfilment of the requirements for the degree of Master of Arts.

....
Supervisor

....

....

Date Oct 15, 1987

Dedication

[illegible] and Dad, who instilled a sense of pride and the spirit of achievement in us all.

Abstract

The use of three dimensional maps in geographic applications has traditionally been limited by the complexities of manual production methods. With the advent of sophisticated computer graphics technology researchers have begun to investigate the use of three dimensional representations in a variety of thematic applications. The study of urban infrastructure has been an area neglected by this increased research. This thesis is a practical application that integrates cartographic methods of display, geographic methods of analysis, and computer graphics technology. The analysis of urban retail change on a high-fashion shopping street street in London, England provides the framework with which the utilization of modern techniques for three dimensional mapping is tested and evaluated. The recent deveoplments in the area of geographic information systems (GIS) has been incorporated into the research design and methodology.

Acknowledgement

Many thanks to those people at the Alberta Bureau of Surveying and Mapping and the Land Information Branch of Alberta Forestry, Lands and Wildlife who provided continued support. As well, many thanks to my supervisor Jean Claude-Muller for the always interesting and personal discussions related to our field of work. A special thanks must go to Denis Johnson for the genuine friendship and support shown during the rather extended length of this project, and to his partner in crime, David Baxter, for the insightful and creative summer we spent together.

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1. INTRODUCTION

1.1 Background

With the rapid increases in computer technology over the past 20 years, computer assisted cartography has become an exciting and expanding discipline. The developing emphasis on thematic applications, and the rise of automated cartographic techniques have been the major factors influencing cartography over this period. The emergence and growth of thematic map research and production is a noticeable advancement. The advent of automation has stimulated the development of several new methods of cartographic display, as well as sharpened old ones. Automation has freed cartographers from many manual drafting tasks, and allowed greater concentration into the areas of map design, map communicatio and spatial data management. The development and application of three dimensioral ereafter 3-D), mapping techniques is an important result of such research.

Three dimensional mapping is an area where much research has been initiated over the past decade. Historically, the rather limited use of 3-D maps has been reserved for physical topographic applications. However, since the early 1970's researcher's like Tobler (1974), Jensen (1978, 1980), and Moellering (1980) have begun to look at 3-D maps as a means of displaying and managing statistical thematic data. Interpreting and displaying geographic data with the 3-D cartographic medium is a progression made possible only through the advent of computing processing techniques.

Currently, numerous computer programs exist to display geographic data as a 3-D cartographic image. However, the vast majority of these are limited in scope, and do not incorporate the theoretical considerations required to allow for a wide flexibility of data applications. As well, most operate in a batch processing mode that restrict the cartographer from making vital subjective decisions during the processing stages. [1] The obvious limitations of such programs and their methods, has led to their limited use by cartographers. Perhaps more importantly though, little innovative research has been addressed by cartographic users of ich programs. The rather narrow themes of study

[1] Batch processing characteristically infers after hours execution of specific programs where all input is stored by the computer for processing at a later time. This does not allow human interaction during program execution.

is a function of such limited applicability. This is noted quite specifically in the literature review. Examples of 3-D mapping programs available include ASPEX, CENVUE, SURFACE II, PILLAR, and SURFER. [2]

With the development of 3-D mapping programs several theoretical and practical questions have been raised as to the applicability of 3-D representations. Practically, there are inherent problems with the visual characteristics of such cartographic objects. These include determining proper viewing azimuth, elevation angle, and degree of vertical exaggeration. Many of the early batch processing techniques were locked into these technical considerations of 3-D map production. Taken from a theoretical viewpoint, the implications of mapping statistical data, absolute or ratio values, is not totally understood. This lack of understanding revolves around the map reader's perception of the 3-D symbol. Historically, there has been much discussion on whether the map reader recognizes the 3-D symbol merely as a point symbol respresenting an absolute data value (ie. height), or as a more complex volumetric depiction of the relationship between several data items (ie. geographic area and percentages). The confusion over the perception of 3-D maps often inhibited their use with thematic data. [3] Accordingly, cartographers have remained weary of using 3-D mapping procedures until these inherent problems have been better researched, defined, and overcome. Needless to say, much of the research into 3-D mapping has not been concerned with effectively presenting statistical thematic data, but has attempted to define objective criteria for solving many of the visual and technical considerations.

[2] A complete list of 3-D mapping programs can be found in: D. Marble ed. *Computer Software for Spatial Data Handling*, Vol. 3. Prepared by the International Geographical Union, Commission on Geographical Data Sensing and Processing, 1982. P. 891-924.

[3] This theoretical consideration is especially prevalent with batch programs like CENVUE. It has been well noted in the literature that mapping an absolute data value with a 3-D volume, particularly when tied to a geographic base, is statistically inaccurate and theoretically inappropriate. Such misuse of area in dealing with statistical data was discussed by Williams (1976). This is further complicated with consideration of the dimensionality of the statistical information. The implications of temporal data is a consideration that as of yet has not effectively been addressed.

1.2 Aims of the Thesis

The emphasis on thematic cartography and the rapid development of computer assisted cartography have been the main factors influencing cartographic research over the past decade. The combined forces of these factors reflects the changing trends in the issues and areas of research currently being explored by cartographers.

> "There has been a trend away from what has traditionally been labelled 'communication and design' research; an approach involving experimental testing of human subjects under controlled conditions. This type of research generally treats very narrow problems. A broader view is now taken of what can legitimately be labelled 'research' in cartography, and there is a wider view of what sorts of questions are worthy of careful, organized study." [4]

This thesis study clearly fits into the new outlook on cartographic research.

There are four principal aims of this thesis research. The first involves the integration of cartography, geography and computer graphics. The concept of the mapping information system and interactive mapping as discussed in the scope of this research involves the interaction of these three disciplines. This relationship is illustrated in Figure 1.1. The interaction of these disciplines can produce mapping methods that incorporate the benefits of cartographic methods of display, computer graphics techniques, and geographic analysis. A system as such will combine the advantages of analysis and display integrated with man-machine interaction. To achieve the goal of obtaining an optimum mapping procedure involving all three disciplines much research needs to be done on such integrated techniques. This research is an attempt to achieve such an integrative mapping method. It is the fundamental aim of this study to develop a mapping information system, based on the inherent advantages of using 3-D cartographic images to investigate multi-dimensional data, that will optimize the advantages of all three disciplines. This approach is based on the assumption that interactive computer systems with input and display capabilities offer the most promising path for the development and improvement of urban spatial analysis. This will

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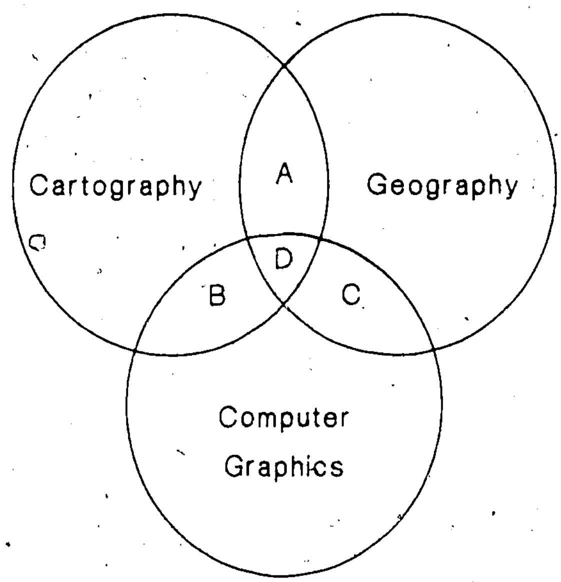
[4] This trend in cartographic research is discussed in:
J. Olson, "Comments on Research Trends", in *The American Cartographer, A Special Issue: U.S. National Report to ICA, 1984*, J. Olson ed., Summer 1984.

Figure 1.1. The relationship between cartography, geography, and computer graphics.



A combination of geographic analytical powers using cartographic techniques

B combination of computer graphic and cartographic techniques to produce output but with no analytical powers

C combines techniques but few applications exist, requires cartographic output

D combines all 3 disciplines - optimum mapping methods incorporating advantages of all 3 approaches

Source : After Moellering, "Interactive Cartography", 1975.

offer the urban specialist maximum flexibility in dealing with the wide range of analytical problems; the ability to consider spatial and temporal characteristics in both the computer analysis and interpretation, and the advantage of augmenting his own knowledge and experience with the tremendous information processing capability of the computer system (Kevany, 1982).

The second aim of the research relates to the cartographic viewpoint. With respect to the recent advancements in technological capabilities, it is the aim of this research to implement and evaluate 3-D cartographic representations as an alternative method for the management, display, and analysis of urban spatial data. It is expected that many of the traditional limitations that have existed in past applications of using 3-D maps will no longer be of concern. Recent technological developments in the computer graphics field have allowed the user to concentrate more on the functions of map clarity and information transfer than the technical considerations of map viewing and map compilation. The design and implementation of a 3-D mapping method using this current technology will provide the mechanism for evaluating the applicability of such cartographic representations.

Thirdly, from a strict geographic viewpoint, it is the aim of this research to effectively display and investigate the process of urban retail change for a high-fashion shopping street over time. A case study was selected that provides the necessary data requirements. The specifics of the case study are discussed in Chapter III. Selected examples are presented in Chapter VI for the mapping methods that were implemented. An evaluation of the results and other potential applications is also included.

The last goal of this research is to provide and evaluate a practical application of the *Intergraph* interactive computer graphics system for computer-assisted mapping. [5] An evaluative application of a computer graphics system will incorporate the recent conceptual changes within the cartographic discipline as well as provide a framework for the future design of other mapping applications.

A brief introduction into the recent changes that have occurred in cartography with the advent of computer graphics, will help to place into perspective the methods

[5] *Intergraph* is a major vendor of computer graphics hardware and software. *Intergraph* is a registered trademark of Intergraph Corporation, One Madison Industrial Park, Huntsville, Alabama.

that were used in achieving the research aims. The concepts that relate to computer graphics techniques and spatial data management are discussed in this chapter. A complete review of past approaches in the use of 3-D maps is presented in Chapter II.

1.3 Relevant Concepts in Spatial Data Management

1.3.1 Interactive Computer Mapping

Recent advancements in computer graphics technology have led to the development of two important research themes in computer assisted cartography. These are **interactive mapping** and **geographic information systems**. The first of these to evolve has been **interactive mapping**.

Interactive mapping, in its simplest form, may be defined as a method of operation in the mapping process, that allows on-line (real time), communication between the cartographer, and the computer, during the retrieval, processing, and display of the map data. Interactive mapping may vary from the basic placement of individual graphic elements by the cartographer, to the most sophisticated computer program in which the cartographer may only determine subjective criteria based on responses he/she receives from the computer. The immediate value of the interactive approach is that it allows for the subjective input and decision making of the cartographer in the production and analysis process. As well, interactive mapping offers the possibility of combining many of the best features of manual and automated map production methods. "It takes advantage of the speed with which computers can perform sequential processing, while allowing the cartographer to take over operations and analysis which are not easily performed in a sequential manner." [6] To fully understand the development and impact of interactive computer mapping several concepts inherent to the process should be discussed.

The concept of initial importance that has developed from computer graphics technology is that of **virtual maps**. The concept of virtual maps is essential to understanding interactive computer cartography. A virtual map may be defined as a

[6] D.J.Dudychak, "The Impact of Computer Cartography", in *Geographica*, Vol. ,1981, P. 116.

directly viewable cartographic image, generally produced from computer graphics techniques, that lacks a permanent tangible reality. Virtual maps are the products of interactive mapping and are displayed on cathode ray tube (CRT) terminals, that allow for real time editing and updating. [7] The concept of virtual maps is discussed by Moellering. [8]

The concept of virtual maps is especially important in any sort of computer processing approach that uses the cartographic image, not only as a final product, but as a vital intermediate step in the analysis of the digital data. Such is the case in this research where the permanency of the visual map product is dependant on the value of the image in identifying internal characteristics within the data set. The temporary nature of the cartographic image is an innate characteristic of any map used for analytical purposes. The virtual map concept is in direct contrast to the more conventional and traditional concept of a real map in cartography. The real map is one which is permanent in nature and has a tangible reality. Consequently, real maps generally are final products in the cartographic process, and are conventionally output as hardcopy map sheets, globes, orthophoto maps, or physical models.

Another concept that is directly dependant on computer graphics technology and remains of vital importance in 3-D mapping, is **dynamic** and **static** maps. This conceptual notion was initially mentioned by Robinson and Cornwell (1966), but is more clearly discussed and defined by Moellering (1980). A dynamic map may be defined as a 3-D cartographic image that affords viewing and analysis through the technological capabilities of surface exploration; or presents for viewing and analysis a sequential representation of the data surface that incoporates the use of change over time display. This latter type of image is referred to as spatio-temporal display (Moellering, 1980).

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[7] CRT terminals are similar to television picture tubes, on which an image is displayed by a pattern of glowing spots produced by directing a beam of electrons at a phosphorescent screen. CRT's are the common display hardware for computer graphics technology. The *real time* environment is one in which the cartographer manipulates the image while it is being processed.

[8] The concept of virtual maps was first introduced in :
H.Moellering, "Interactive Cartographic Design",in *Proceedings of ACSM 1977*,1977,P. 516-530.
and discussed further in :
H.Moellering, "The Real-Time Animation of Three Dimensional Maps", in *The American Cartographer*, Vol.7, No.1, April 1980, P.67-75.
H.Moellering, "Strategies of Real-Time Cartography", in *The Cartographic Journal*, Vol.17, No.1, June 1980, P.12-15.

A complete discussion of the theoretical and practical considerations of dynamic maps is included in Chapters II and IV. It will suffice for now, to introduce this concept and stress it's importance in the development of 3-D computer assisted cartography, and particularly it's relevance to the research objective of this thesis.

1.3.2 Geographic Information Systems

A second area of major research that has developed out of the application of computer graphics technology to geography is **geographic information systems**. The geographic information system (hereafter GIS), is a commonly used tool in the spatial sciences, for the input, storage and retrieval, manipulation and analysis, and cartographic display of spatial data. The concept of GIS is a natural development of the geographer's need to efficiently handle large amounts of spatial data.

The original notion of the GIS was first introduced to the geographic community in the early 1970's by Roger Tomlinson. Tomlinson's Canadian Geographic Information System (CGIS) was the first serious attempt to handle substantial amounts of map data by computer processing techniques. The main design approach used in CGIS was simply to transform map data into a structured, non-graphic format that was ameniable to electronic data processing (Marble et al, 1984; Tomlinson, 1976).

Over the past decade the design and application of GIS's has become increasingly complex and sophisticated. Much research has been initiated in the area of data base design and data management. The marriage of computer graphics technology and data base management concepts has come to characterize the latest definition of GIS. Several large scale GIS products are commercially available to the cartographic community today. A GIS incorporates much more than a non-graphic or graphic representation of spatial data. Increasing research in GIS development and applications has led to a much needed definition of a GIS's components. "Today, geographic information systems often are comprised of quite sophisticated computer software and hardware, but they all are oriented towards the processing of space-time data and contain the following major components :

1. A data input subsystem.
2. A data storage and retrieval subsystem which organizes the spatial data in a form which permits it to be quickly retrieved by the user for subsequent analysis, and which permits rapid and accurate updates to be made to the spatial data base.
3. A data manipulation and analysis subsystem which performs a variety of tasks such as changing the form of the data through user defined aggregation.
4. A data display subsystem, which is capable of displaying all or part of the data base, as well as manipulated data in cartographic form." [9]

An important idea which is mentioned earlier is vital to the concept of GIS. Practically, the cartographic image is only a processing step in the analysis of spatial data. The cartographic image no longer exists only as the final product. The four primary components, as defined by Marble, work in unison to produce an information system of the data set.

Traditionally, the GIS approach has been researched and discussed in terms of massive data sets. However, the term GIS does not necessarily incorporate only the use of large data sets. Most GIS development over the past decade has been of the "in-house" fashion, and was concerned with specific applications that were often inherently small in scale. [10] Consequently, most GIS's were structured around highly specialized needs for a limited number of users. In fact most of the commercially available GIS software that exists today is special purpose in nature (Wilson, 1984). It is important to remember, that the "definition of a GIS is a functional one, and aside from a clear focus on space-time data, does not rest upon questions of scale or content." [11]

Throughout GIS research many terms have been introduced to deal with specific subsets within the GIS realm. A prime example, and one that is very popular today, is the land related information system (hereafter LRIS), or land information system (hereafter LIS). The LRIS exists as a functional subset of the more generic GIS. This is primarily because of it's reference to scale. The LIS or multi-purpose cadastre, is concerned with

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[9] D.Marble, "GIS and LRIS: Differences and Similarities", in *FIG: International Symposium on Land Information Systems Proceedings*, October 1984, P.3.
[10] The term *in-house* refers to research or development undertaken internally within one computer installation, site, or company. Most in-house research tends to be small in scale and for very specific applications.
[11] D.Marble, "GIS and LRIS: Differences and Similarities", in *FIG: International Symposium on Land Information Systems Proceedings*, October 1984, P. 4.

legal information at a very large scale (ie. 1:1000).

Another term that has been used fairly indescriminately in the GIS context is the mapping information system (hereafter MIS). It has often been used in exchange with GIS without thought of function or consequence. Within the context of this research the term MIS is used specifically as a functional subset of the more comprehensive GIS. The MIS concept applied in this study is distinct in two main ways from being a complete GIS. Firstly, the four necessary components identified by Marble are not completely developed and integrated with each other. [12] Secondly, and more importantly, as the term MIS implies, there is a significant weighting on the value of the cartographic image as the analytical research tool. The concept of vital importance here is **visual analysis.** Here the analysis of thematic data and it's geographical relationships, and in this case the temporal relationships, is immediately achieved through the 3-D cartographic medium. This notion is somewhat opposed to the more conventional definition of analytical processing using strict mathematical and numerical methods. To analyze, taken in its more literal meaning, is to separate into its parts in order to identify or study its structure. While the concept of a MIS accepted in this study does include some basic data analysis, the major emphasis is on the visual analysis of the 3-D cartographic image by the selected data specialist.

Visual analysis may be thought of as performing the function of cartography in an analytical fashion. Here the intuitive talents of the geographer are of utmost importance. This concept is similar in many respects to Bertin's idea of graphic processing. [13] The data is transformed into a graphics display, where the user can analyze and order the data dependant on inherent characteristics that are brought out by its visual appearance.

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[12] This is due in part to the fact that the scope of this study has limited the development of the computer software required to fulfil GIS requirements.
[13] Visual analysis, as discussed here, parallel's Bertin's concept of graphic information processing in which data is transcribed, simplified, and interpreted to extract both intrinsic and extrinsic information about the data. More information can be obtained from :
J.C.Muller,"Bertin's Theory of Graphics / A Challenge to North American Thematic Cartography", in *Cartographica*, Vol.18, No.3, 1981, P.1-8.
For a more complete explanation of Bertin's concept of graphic information processing see :
Jacques Bertin,*Graphics and Graphic Information Processing*,(New York: DeGruyter & Co., 1981).

The concept of visual analysis will be discussed in more detail in Chapter IV. The process of visual analysis remains a critical concept in the development of the MIS applied in this research.

1.4 Structure of the Thesis

The format of any formal treatise is wholly dependant on the field of study and the process of research. In the context of this research, and particularly any study that involves the use of computer techniques, it is vitally important that the introductory statements present the specific area of research to the readers. It is perhaps even more critical that the concepts of importance and the aims of the research be clearly identified. With the above requirements satisfied this thesis will unfold in the following manner.

Chapter II will acquaint the reader with the historical developments of 3-D mapping, culminating in its evolution as a research tool used for the management of spatial data.

Chapter III will identify the specific case study used for this research, and familiarize the reader with the inherent problems involved in attempting to categorize and manage multi-dimensional spatial data. The specific methodology that was undertaken to achieve the aims of research will be presented.

The specifics of computer hardware and software used in the case study, and the considerations of using computer graphics techniques as application tools will be discussed in Chapter IV.

Chapter V will identify the conceptual planning that formed the basis of the research design, by discussing the specific analytical techniques used. A overview of the resultant application software package developed to meet the objectives of research will be presented.

Chapter VI will present several application results that were achieved and discuss each in terms of practical cartographic, geographic, and technical considerations.

Chapter VII will include a general overview and discussion of the study process; an evaluation in terms of the cartographic versus geographic objectives; and an examination of the problems and limitations of such research. Summarization of the study will include suggestions for future study and enhancements, and will conclude with a final statement on the role of mapping information systems and 3-D mapping techniques as a viable alternative (research tool) for the management of spatial information.

A bibliography of all relevant and referenced works will complete the thesis body in Chapter VIII.

The context of this application study necessitates a lengthy list of appendices that will include the following :

i) a glossary of terms that are relevant to the specifics of research

ii) a complete listing of the Standard Industrialization Classification (SIC) derived for the case study as well as complete statistics on the classification scheme elements

iii) complete base map for the case study area.

2. LITERATURE REVIEW

2.1 Introduction to 3-D Mapping

"Since the 18th century the map has been used as a tool to show spatial distribution of physical, social, and economic phenomena. Such maps, which present a particular theme, are often distinguished from the topographic map by the term thematic maps." [14] Some cartographers have said that thematic cartography begins where topographic cartography leaves off. A thematic map generally is referenced to a topographic base. It is quite apparent the reliance of thematic mapping upon topographic cartography is chronological as well as physical. Correspondingly, 3-D mapping owes its origins to topographic applications. Initial applications of 3-D maps were simply attempts to give a 3-D illusion of relief to topographic maps. Therefore, any discussion of the development of 3-D mapping requires a brief examination of the progression of 3-D topographic applications.

Since the turn of the century block diagrams and 3-D maps have been common in geologic and geographic literature. With only a few exceptions, the primary goal of 3-D research up to the 1960's, had been in the three dimensional presentation of relief. During this time cartographers were concerned with establishing new techniques that would give a realistic three dimensional look to landform maps.

In 1932 Kitiro Tanaka presented a technique that would display a topographic map as a set of inclined contour planes (Tanaka, 1932). This is a method that is still taught in various introductory cartography courses. Schou (1941) followed soon afterwards concerning himself with obtaining the proper perspective in block diagrams. The concept of angular versus isometric perspective introduced by Schou is a recurring theme throughout the literature on 3-D mapping. It has become an important question in research during the thematic applications of the 1970's, and is discussed in full later on. Tanaka (1950) presented a new technique for 3-D relief presentation incorporating the use of illuminated contours (Tanaka, 1950). As is the case with other techniques of this period it could also be applied to the representation of thematic surfaces, yet was rarely done. Robinson and Thrower (1957) modified Tanaka's inclined contour method to

[14] A.G. Hodgkiss, *Maps for Books and Theses.* (New York: Pica Press, 1970) P. 13.

incorporate hill shading and a light source. Lobeck (1958) published a book that dealt with block diagrams. He concerned himself primarily with the perspective question again. In 1958 John Stacy added to Lobeck's research by presenting a technique for developing block diagrams of landform areas in isometric perspective. This was closely followed by Yoeli's first article on relief shading (Yoeli, 1965). Yoeli would publish several articles on relief shading techniques throughout the 1960's, 1970's, and 1980's, incorporating the use of the computer with his later research.

It is obvious that because of the nature of cartography during the early 20th century, three dimensional mapping research was concerned primarily with developing new manual techniques for the use of 3-D mapping in landform applications. It is not until the advent of thematic research and computer applications of the 1960's that 3-D mapping research began to evolve. This literature review will continue by providing a brief outline of the early issues in thematic applications of 3-D mapping, evolving into a full examination of the renewed interest shown in the 1960's, and the recent research of the 1970's and 1980's. This outline will provide a valuable historical and practical framework within which the specific aims of this research can be examined.

2.2 Early Issues in 3-D Cartographic Research

The use and development of 3-D representations is well documented throughout cartographic literature. Early efforts at 3-D mapping were attempts to create the illusion of a third dimension via a two dimensional medium. As noted earlier, the major emphasis before the 1960's was on landform or topographic applications. However, there are four definite exceptions where researchers, while developing new mapping techniques, were not solely concerned with producing a three dimensional image of the terrain.

In 1922 Sten De Geer published an article that was basically in response to the need for displaying quantitative data effectively. De Geer proposed the use of 3-D representations based on the existing theory of dot method. He believed that the graphical representations of spheres could be drawn in a manner coexistant with dots. However, his method was neglected by the cartographic community until 1928 when Guy Harold Smith published his famous "Population Map of Ohio for 1920" utilizing the same basic technique as De Geer. The only distinction between the two methods was

Smith's alteration of the symmetrical arrangement of dots utilized by De Geer, to an asymmetrical arrangement of dots." [15] A note worthy of mention is the dimensional inconsistency portrayed in this method. Smith perceived the spheres as circles with the respective centres accurately positioned over the appropriate city locations. However, if the spheres were accurately perceived as a three dimensional symbol their relative locations would be positioned by consideration of the point of spherical tangency of each sphere - plane interface (McKay, 1975). In other words, the resting point of each sphere should be equivalent to the positional location of the respective cities on the map. Three dimensional figures have been interspersed with two dimensional dots.

Two other exceptions where cartographers were not soley concerned with terrain representations, involve attempts to resolve the dimensional inconsistency portrayed in previous methods. In 1939 Erwin Raisz presented an article which would address this problem through the use of cube like symbols referred to as block piles. It was his desire to provide a technique that could overcome the lack of commensurability and the subdivision difficulty inherent with the use of spheres. The block pile symbols are displayed in a three dimensional manner on a two dimensional base. However, the imaginary base upon which the block piles rest on his map is 45 degrees off the plane on which the base map has been constructed (McKay, 1975). This disparagement, while perhaps not immediately noticeable to all map readers, should be recognized as dimensional inconsistency.

Wilbur Zelinsky utilized an isometric symbology in an article published in 1961. His use of isometric cubes on a two dimensional base was an attempt to effectively display thematic information. "The use of these particular volumetric symbols did offer the possibility of overcoming the weakne presented in the works of Raisz. However, Zelinsky was apparently unaware of this and proceeded to induce the same problem in his cartographic output." [16] The plane of the two dimensional base map lies approximately 60 degrees off the imaginary plane upon which the isometric cubes rest. The volumetric symbols appear to be floating in space.

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[15] R. McKay, *A Holographic Solution to the Problem of Three-Dimensional Display in Thematic Cartography*, M.A. Thesis, Department of Geography, Michigan State University, 1975. P.30.
[16] R. McKay (1975), P.33.

The 3-D work of these early thematic cartographers was plagued with the problem described as dimensional inconsistency. This problem was an obvious result of the lack of knowledge and understanding in the study of 3-D representations. This problem and others were not fully researched until the renewed interest of the 1960's.

2.3 Renewed Interest

The advent of the 1960's brought renewed interest in the application of 3-D maps to thematic cartography. In 1966 the first of four reports was published by George Jenks for the Office of Naval Research. These four reports mark the beginning of modern cartographic research into three dimensional mapping.

The first report entitled "Three-Dimensional Map Construction" presented a technique for manually constructing three dimensional maps. Jenks and Brown (1966) suggested the flexibility of three dimensional map applications for thematic data.

In July of 1967 the second report was published by Jenks and Caspall. For the first time cartographers were not merely concerned with the construction technique, but with the theoretical considerations of the process. Using a **communication and design** type of research, they attempted to study vertical exaggeration in 3-D maps and how people perceived it (Olson, 1984). They described no distinct criteria for selecting appropriate vertical exaggeration but concluded that it was a necessary element of 3-D mapping and warranted further research. Shortly afterwards in September 1967 Jenks and Crawford published the third report on 3-D mapping entitled "Viewing Points for 3-D Maps". This report studied the elevation angle and viewing azimuth required in 3-D maps, and set forth a series of guidelines for selecting these viewing points. This report also reintroduced the perspective concept so relevant in earlier 3-D research. The report concluded that isometric and angular perspective offered little difference in 3-D representations when primary concern was choice of vertical exaggeration, elevation angle, and viewing azimuth.

With the publication of the "The Final Report for 3-D Maps" in 1971 Jenks and Steinke had reintroduced the concept of 3-D mapping to cartography, and established the three visual characteristics as the primary themes for future research. In addition, this final report summarized the findings of the previous reports and offered new information relating to the aesthetics of 3-D mapping. Up to this time the 3-D map was a function of the skill of the cartographer and the technique used in producing the map. Jenks suggests in conclusion that the 3-D map may be reserved for the computer and that research may ultimately point in that direction.

2.4 Recent Issues and Concerns

The arrival of the computer age to cartography in the early 1970's shifted the 3-D mapping research emphasis into two main themes.

The first area of increased research was the natural application of computer technology to developing new techniques for producing 3-D representations. This is an emphasis that continues today and is unlikely to stop for many years. Of course, research as such is highly technologically dependant and somewhat reflective of the more theoretical research occurring in other areas of the cartographic discipline. This thesis research is one such example of an application induced by new technological developments.

During the early 1970's 3-D mapping programs were being developed at a very rapid rate. Construction techniques and procedures were being developed that had previously been impossible. As noted earlier, the majority of these 3-D mapping programs were developed in a batch processing environment. Due to the rapid nature of such developments, the theoretical and conceptual implications of the 3-D cartographic image were not often fully understood. Consequently, the implications of such technological developments necessitated deeper study into the concept of 3-D representations.

The second main research theme that developed during this period involved the visual characteristics of 3-D mapping (as introduced by Jenks). The majority of research during the 1970's was concerned with studying and defining guidelines for the proper determination of the visual parameters characteristic to 3-D maps. With this research emphasis in mind, and before a review of the relevant literature, it is appropriate that these visual parameters be clearly defined.

There are **three** main visual parameters that are important in clearly understanding and displaying 3-D cartographic images. They are **viewing azimuth, elevation angle,** and **vertical exaggeration.**

Viewing azimuth refers to the lateral position of the viewer with respect to the map object (Rowlés, 1978). This is sometimes called map rotation or orientation. Azimuth may be defined as the degree of rotation around the vertical axis (Z). Azimuth in its literal definition is the angular distance east or west of the north point on a map. In this context it is appropriate. Viewing azimuth as it relates to 3-D maps is illustrated in Figure 2.1.

Elevation angle is often interchanged with altitude and tilt to describe the location of the viewer above or below the object surface. This is also described as the angle of the viewing position relative to the horizontal plane of the 3-D surface. In the example illustrated in Figure 2.2 the horizontal plane is represented by the X,Y plane. The Z axis represents the vertical height of the symbols. The elevation angles of the three maps represent the degree each viewpoint has been rotated around this X,Y plane. The amount of elevation angle used in a 3-D image is perhaps the most vital factor in determining that image's 3-D impression.

The final parameter of vital importance in dealing with a 3-D cartographic image is the level of **vertical exaggeration** used to create or view the object. Vertical exaggeration can be defined as the scaling of vertical points (Z values) by a constant factor over a defined map area. Because vertical changes are relatively small compared to the horizontal distance in a map area, exaggeration of the vertical heights is often required to give a presentable and realistic appearance to the 3-D map. It is important to note that with vertical exaggeration the horizontal scale of the map area does not change. Vertical exaggeration is illustrated in Figure 2.3.

The overriding theme of the research in the recent era is to identify each parameter while stressing the importance of the interrelationship between all three parameters in maintaining the 3-D impression of the map product and achieving optimum map clarity by minimizing surface blockage. This notion is clearly evident in all the literature referenced during this period.

As early as 1973 Crawford and Marks began to investigate the visual effects of geometric relationships in 3-D maps (Crawford, Marks, 1973). This study was primarily concerned with the choice of perspective (angular, versus isometric), and the

Figure 2.1. An Illustration of viewing azimuth. Map orientation is changed by 30° about the Z axis with each surface.

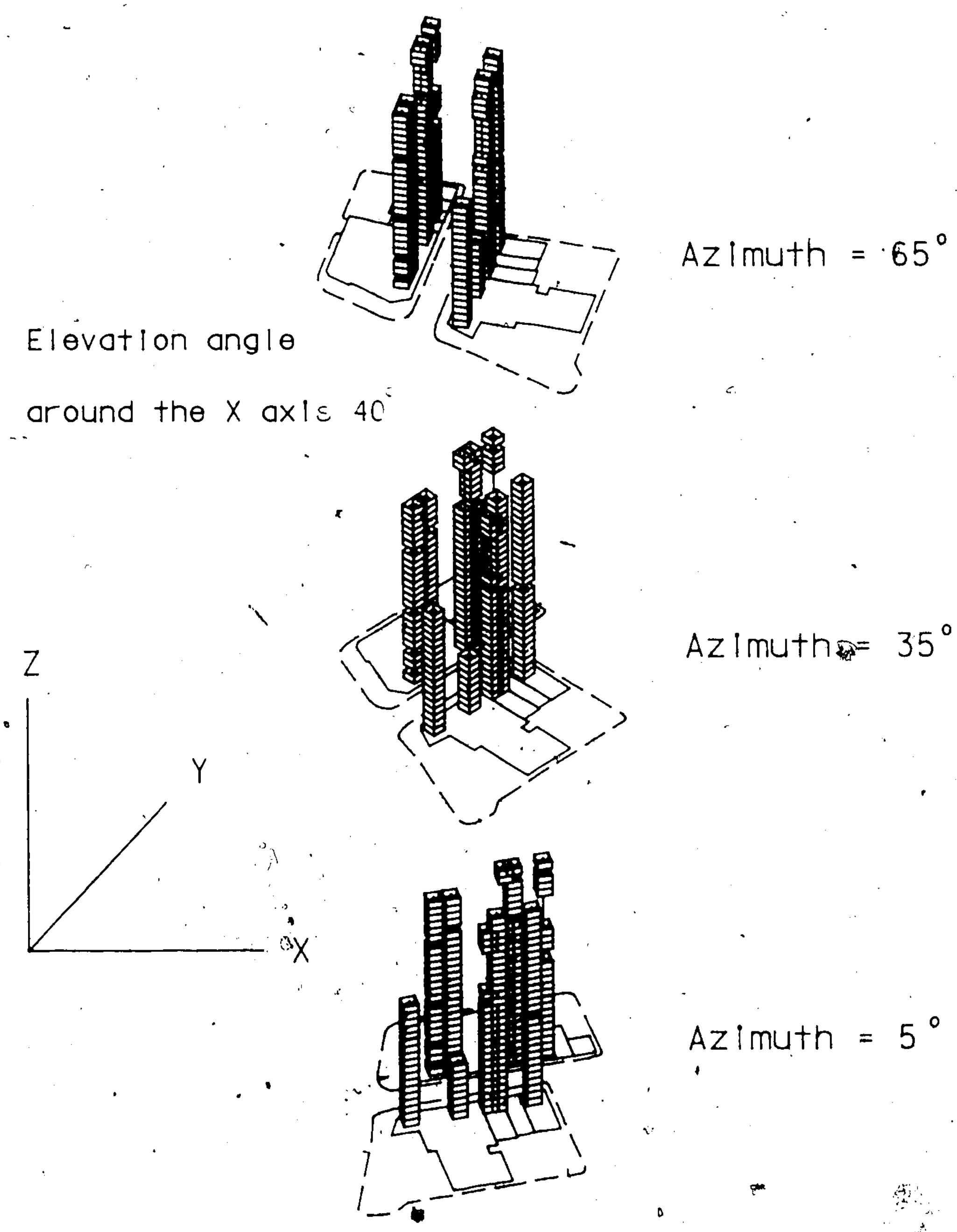
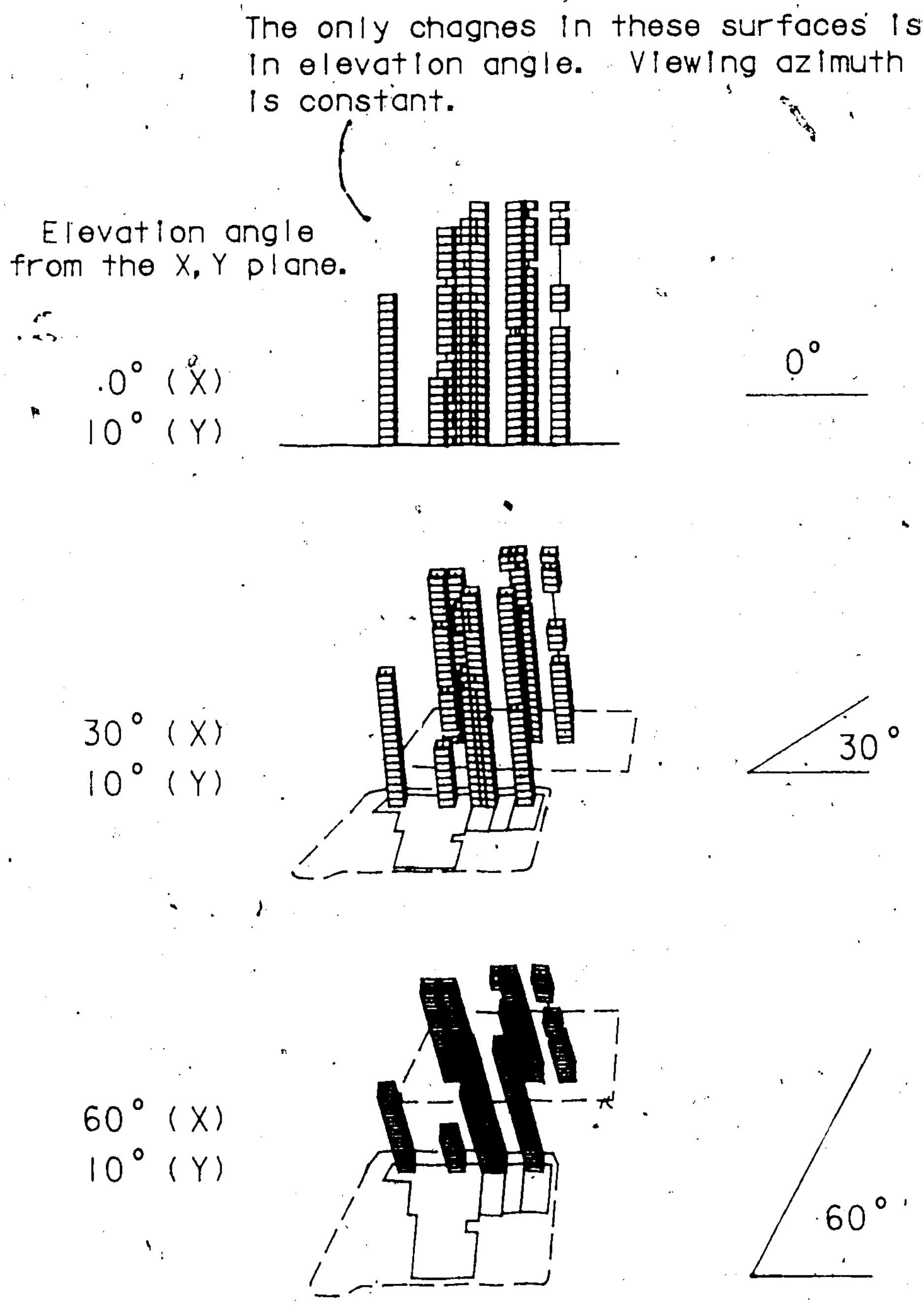


Figure 2.2. An Illustration of elevation angle.



Source : Modified from Jenks and Crawford (1973).

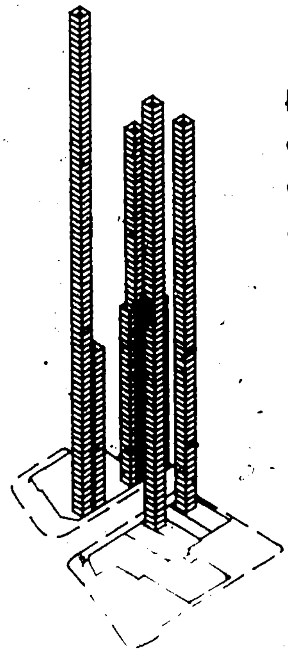
Figure 2.3. An Illustration of vertical exaggeration using thematic data.

The same data set is used in all 3 surfaces.

Note that viewing azimuth, elevation angle, and horizontal scale is constant.

Vertical Ratio

VE = 1:4

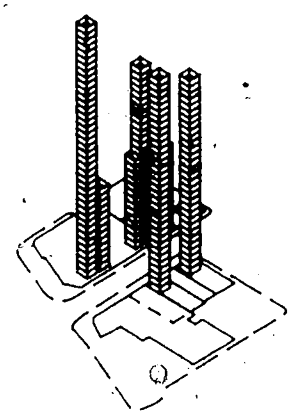


4 cubes = 1 year

1 year = 10 metres

1 cube = 2.5 metres

VE = 1:2

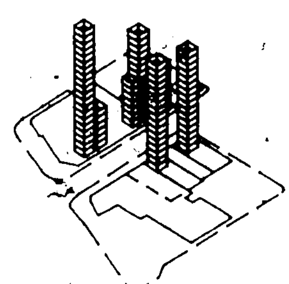


2 cubes = 1 year

1 year = 5 metres

1 cube = 2.5 metres

VE = 1:1



1 cube = 1 year

1 year = 2.5 metres

1 cube = 2.5 metres

determination of elevation angle, viewing slope, and the amount of vertical exaggeration in creating 3-D maps. General guidelines were presented.

Bohannan (1976) concerned himself specifically with studying vertical exaggeration in perspective block diagrams. He sought to determine whether a relationship existed between vertical exaggeration and terrain relief. However, this study was restricted to a physical landscape orientation and accordingly his rather general results were of limited applicability.

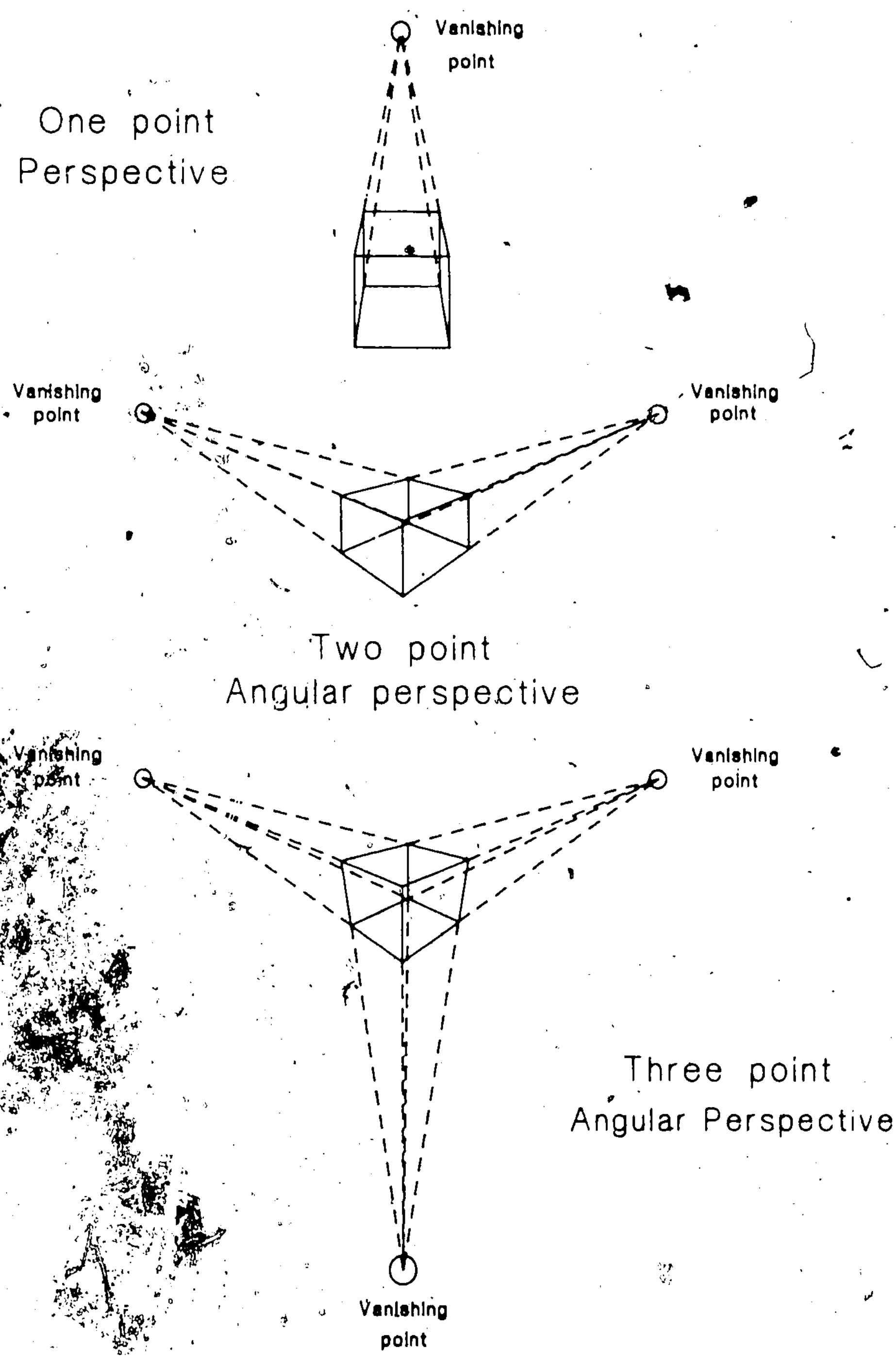
In 1978 an influx of 3-D research appeared in the cartographic literature. Rowles (1978) investigated the role of visual parameters in the perception of perspective block diagrams. She explored in detail the problem of choice of perspective in 3-D maps. The dichotomy between focused (angular) and isometric (parallel) perspective is clearly identified. As this has been a recurring theme throughout the literature a brief discussion of the distinction seems appropriate at this time.

"**Focused perspective** can be defined as an image with a set of mutually parallel lines that recede from the eye of the viewer to converge at a single point, a vanishing point, with the size of the object diminishing in proportion to its distance from the spectator's eye." [17] A 3-D map with focused perspective is composed of lines that converge towards one, two, or three vanishing points. Drawings as such are said to use 1, 2, or 3 point perspective. The result is a realistic representation of what the human eye would see if the object were truly three-dimensional. However, because of the changing scale across an object mensurability is impossible. Variations in focused perspective are illustrated in Figure 2.4.

Isometric perspective occurs when all lines parallel in the object appear parallel in the drawing, and all lines vertical in the object appear vertical in the drawing. It differs from the focused perspective in that no vanishing points are involved in its construction. If the vertical and horizontal scale are equal isometric perspective has the added advantage of commensurability along all dimensions (X, Y, and Z). Historically, 3-D representations have made most use of the isometric perspective. This is mainly because of it's ease of construction and the commensurability factor. The distinction between perspective alternatives is illustrated in Figure 2.5. Perspective remains a

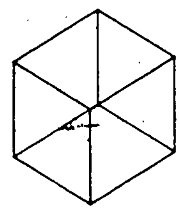
[17] R. Rowles, P. 31.

Figure 2.4. Variations in focused perspective

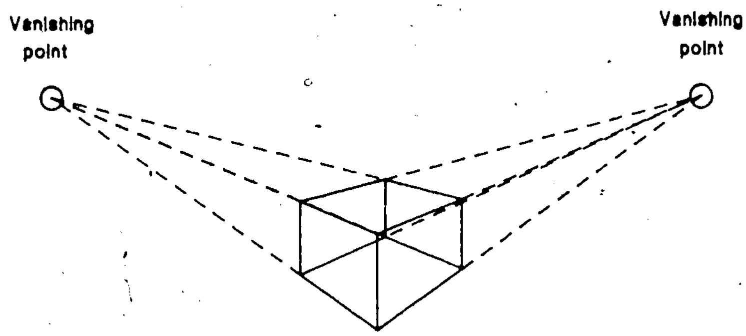


Source : After Rowles, "Perception of Perspective Block Diagrams", P.32.

Figure 2.5. Distinction between perspective alternatives.



Isometric Perspective



Two point
Angular perspective

subjective decision that cartographers must make when constructing 3-D representations. However, most 3-D computer mapping programs that exist today, while offering a choice, traditionally default to the isometric perspective.

Rowles concludes that the choice of perspective depends on the application of the map product, and that both have little effect on the perception of surface information. It should be noted that the concept of map perspective remains a fundamental decision in the development, understanding, and use of any three dimensional product.

Worth's research was concerned with determining a vertical scale, or level or vertical exaggeration, for graphical representations of 3-D surfaces (Worth, 1978). Using the hypothesis that map readers consistently overestimate heights and slope angles, and that the need for vertical exaggeration in maps is caused by this overestimation, it can be determined through tests, that map readers prefer to see perspective maps with the same proportion of height to length for a wide variety of surface types. Correspondingly, an aesthetic 3-D effect is consistently achieved through the use of this height to length proportion. Worth concludes that map readers prefer to see 3-D surface representations in a particular format with the length and height of the map in the proportion 1:0.292. He presents this as a general guideline for achieving optimum vertical exaggeration in all 3-D maps. For the first time since vertical exaggeration was introduced by Jenks and Caspall (1967) as a visual parameter for 3-D maps, a oartographic guideline has been presented for standard use.

Congruent with the ongoing research into the visual characteristics of 3-D maps undertaken during this period Monmonier (1978) introduced the concept of viewing azimuth as the most important visual parameter in establishing map clarity in viewing 3-D cartographic images. He presents several methods to determine an appropriate azimuth with the the hypothesis that once the viewing azimuth is defined the solution space for determining an appropriate vertical exaggeration and elevation angle would be minimized and could easily be achieved. Monmonier argues that the viewing azimuth is directly dependant on the data set displayed, while vertical exaggeration and elevation angle remain slightly more objective criteria with which standard guidelines have previously been presented in the literature (Jenks and Crawford (1967), Crawford (1973), and

Worth (1978)). Monmonier's research helps to clarify the interaction and relationship of the three vital visual characteristics of 3-D maps. However, his rating of importance for each is clearly dependant on the construction technology of the day. The process for constructing 3-D maps at this time involved the use of batch computer programs where all three criteria were defined prior to viewing the data surface. Consequently, any attempt to standardize the construction process, including reducing 3-D blockage and increasing map clarity, would only help to minimize the amount of redundant processing required to produce a valuable and effective 3-D map product. With the introduction of interactive mapping and the developing technology in computer graphics, the process of defining all three visual characteristics has become a function which can performed at the graphics workstation. The problem has evolved into a subjective decision that can easily be performed by the cartographer in real time when viewing the 3-D map image. The capabilities to interactively rotate, zoom in/out, and pan a 3-D map image in real time preclude the need for prior establishment of distinct values for viewing azimuth, elevation angle, and vertical exaggeration. It is important to note here that the 3-D product constructed by most current technologies is in fact stored as a 3-D image. It is not merely a two dimensional representation of a three dimensional surface as was commonly created by earlier batch processing techniques.

Nevertheless, while Monmonier findings are somewhat dated by technology, his research clearly identified the salient characteristics and the relationships involved in viewing 3-D map images effectively.

Jensen's research appears in direct response to the problem of defining appropriate visual characteristics in 3-D maps (Jenson, 1978). He introduces the concept of 3-D stereoscopic choropleth maps to thematic cartography. Three dimensional mapping of the recent era is continually attempting to determine effective viewing azimuth, vertical exaggeration, and elevation angle in an effort to minimize the amount of surface blockage, while maintaining the three dimensional illusion of the representation. Only in this way will statistical information be clearly presented to the map reader. These problems exist as a distinct limitation in the 3-D mapping process. Similarly, these limitations exist because cartographers dealing with 3-D mapping have constrained their research to 2-D maps which give the impression of the third dimension. Jensen presents a 3-D method for the portrayal of stepped statistical surfaces which includes none of the limitations of contemporary 3-D maps. The stereoscopic map exists as a special purpose alternative to the 3-D map surface.

By 1980 Jensen had expanded his research to include both continuous and stepped surfaces with either a planimetric or oblique orientation. The mensurability of such products and the lack of surface information blockage remain immediate advantages of such a map product. However, several inherent limitations hindered Jensen's application. The necessity for stereoscopic viewing, and the use of a stereo pair of lenses, is in itself a distinct limitation. As well, the obvious construction drawback exists in that two maps must be compiled and produced instead of one. And ultimately, the map product is totally dependant on the viewer's ability to see stereo. As well, the 3-D image is greatly exaggerated in a vertical manner. Accordingly, the steroscopic statistical map exists as a 3-D product confined to special purpose applications. Jensen's research may be viewed as a major step in the natural evolution of a 3-D map product.

Moellering has perhaps made the greatest impact on 3-D mapping during the recent era. Beginning with articles as early as 1975 Moellering has taken 3-D map research towards the evolution of real time 3-D map production, the real time animation of 3-D maps, and the theoretical considerations of using such map products. Moellering's earlier research investigated the implications of interactive computer design on the mapping process. It is here he introduced the concept of virtual and real maps. Moellering's research was one of the first to address the question of the computer map product and its role in cartography and analytical geography. Much of his research forms the basis of this thesis study (Moellering, 1975, 1977, 1980).

Increasing technological developments in computer processing techniques have made it feasible to display 3-D cartographic objects dynamically. As noted earlier, with dynamic display capabilities the choice of the three visual characteristics is no longer a major pre-processing concern. Infinite viewing points incorporating both azimuth and elevation angle, are interactively available to the map user.

The dynamic display of the 3-D cartographic image can be obtained in two ways. If the cartographer's object is of a single Z surface (temporally static), dynamic viewing is perceived as **surface exploration**. The capabilities to explore a surface (rotate, zoom, and pan), is a function available in most 3-D mapping software and hardware today. Similarly, the sequential representation of a surface that changes over time can be accomplished and is referred to as **spatial temporal display**. Such computer graphic displays allow the cartographer more flexibility than conventional static maps. As the complexity of the surface increases, the potential benefit of such dynamic control also increases (Moellering, 1978, 1980).

Moellering also suggests that the more sophisticated use of such cartographic animation is for analytical purposes, usually related to the examination of spatial process in geography. The dynamic animation of 3-D objects offers an alternative way in which to recognize sequences of change in order to formulate spatial hypotheses that can be tested with other statistical analysis. In this context the 3-D map has evolved from being a method of display to functioning as an analytical research tool. This concept put forth by Moellering has developed into the term **visual analysis** under the context of this thesis research. While the underlying concept is quite similar, the process of achieving such visual analysis has been developed from the notion of the GIS. The resultant MIS incorporates the idea of the 3-D map as an analytical map product with the theory of spatial data processing.

3. THE URBAN CASE STUDY

3.1 Introduction to the Data Set

The case study chosen for this thesis research involves the study of urban infrastructure. In traditional urban geography infrastructure is defined as the essential elements that make up an urban entity. These are the various commercial facilities, the educational and research establishments, and the physical utilities such as the transportation network, the communication network, and buildings (Yeates, Garner, 1976, P. 119-123).

Urban infrastructure is an area of study that remains neglected in cartographic research. While many urban mapping studies have been undertaken most are concerned with either the establishment and placement of base positional data or the symbolization and representation of quantitative data for specific locations. Little has been done on the application of qualitative data sets.

The characteristics of using a qualitative data set are well suited to the theoretical considerations of 3-D cartographic representation as well as the technological capabilities of the tools to be used. The specific data set chosen for this thesis research involves the classification and development of retail functions along a high-fashion shopping street over a selected period of time. The commerical shopping ribbon of interest is Bond Street. Bond Street, comprising both Old and New Bond Street, is a high order retail shopping street in the posh Mayfair district of London, England. The street is bounded by Oxford Street to the north and Picadilly Street to the south running in an north-south direction between the two. Twelve cross streets intersect with it to create 14 well established city block frontages. The traditional 19th and 20th century architecture of each block ranges from 2 to 6 stories in height. Bond Street is little more than a 1/2 mile in length. However, both Old Bond Street and New Bond Street exist as one retailing ribbon. Approximately 190 different ground floor establishments are currently located on the shopping street. However, throughout the study period as many as 389 different addresses have been established on the street. The difference between this and the number of current addresses can be explained by the temporal process of retail growth in the form of establishments disappearing, subdividing, and agglomerating. This unique addressing characteristic is discussed in the procedural description section of this chapter.

The study period chosen for the data set is from 1840 to 1980. These dates were based on two years for which the most reliable information on shop type and location could be obtained. The starting date of 1840 represents the approximate publication date of the Tallis London Street Views (1840) which contains a street directory of establishments and activity descriptions. The primary source from 1840 to the ending date was the Post Office London Street Directory. It provided annual publication lists by postal street address of the name and function of proprieters along the street. The ending date of 1980 represents the most recent time period during which complete field observations were undertaken on the street (Johnson, Baxter, 1986). The data set collection process and its unique characteristics are discussed later in this chapter.

It is important to note that this research was originally initiated by Dr. Denis Johnson, Department of Geography, University of Alberta in an effort to study temporal change of retail establishments and functions on the Bond Street shopping ribbon.[11] The existing data set was chosen because the characteristics of the data are aptly suited for 3-D cartographic representation. The inherent complexity of mapping change over time in an urban landscape goes beyond the bounds of traditional retailing and cartographic research. With the sophisticated research and display tools utilized here an informative analytical examination of complex retailing structures can be ... ated. Research as such was previously impossible for a data set of this size.[19] However, most importantly the multi-dimensionality of the data can be reflected well through the dynamic nature of the mapping system capabilities. A reduced base map of Bond Street is provided in Figure 3.1 as a geographical framework of reference. A complete base map including all available planimetric features is presented in Appendix 3.

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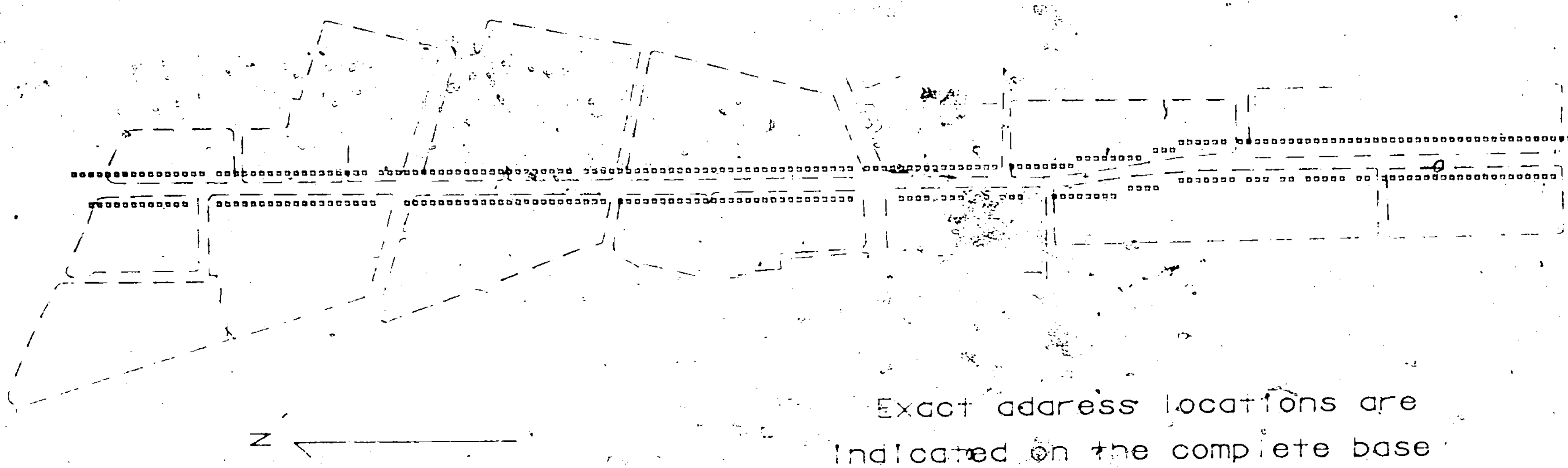
[11] The distinction between *establishment* and *function* requires identification at this time. *Function* refers to the type of activity. It has no bounds of location or ownership. *Establishment* infers particular ownership of a specific function. This most commonly refers to a particular proprieter involved in a specific function.

[19] The entire cleaned data set, including both five and one year interval data, contains 11,147 individual data items.

Figure 3.1. The Bond Street base map.

- - - Sidewalk block boundaries

Address locations



Exact address locations are indicated on the complete base map in Appen x 3.

Source : British Orcnance Sur.ey

3.2 Methodology

A noted previously, a review of the literature identifies an obvious neglect in the application of 3-D cartographic research to urban infrastructure study. This void of urban cartographic research necessitates a systematic approach to the study of urban retailing structure utilizing the tools of interactive computer mapping and spatial data management. A system development methodology as such must first start by clearly identifying the problems of study and establishing a hypothesis for the study theme. Once formulated it is important to identify the procedural steps involved in this hypothesis for the manipulation and processing of the data set. Only then can the research be tested and evaluated in terms of applicability, theoretical relevance, and analytical performance. The methodology approach is presented in Figure 3.2.

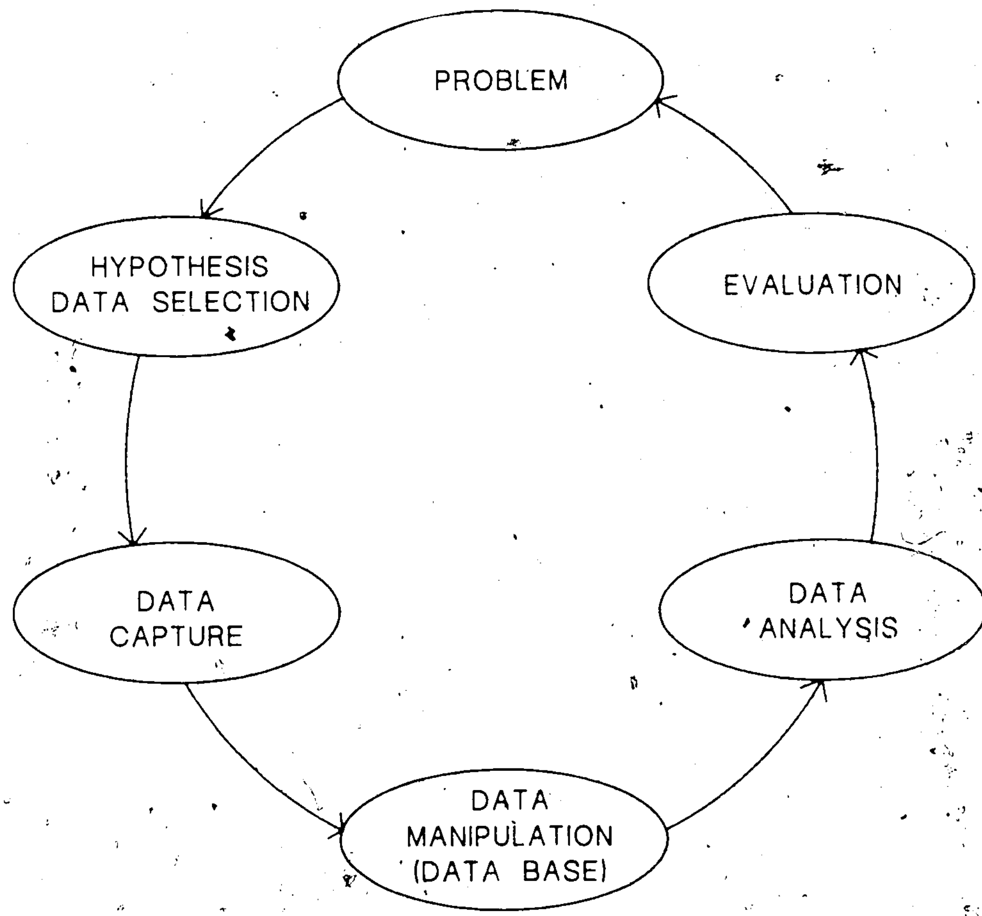
3.2.1 Problem Observation

The observation of the problem may be defined from two disciplinary approaches. These are the urban geographic viewpoint and the more technical cartographic viewpoint. A discussion of each is appropriate at this time.

The observed problem or goal of the research from a strict urban geographic viewpoint is to effectively measure the temporal change/development of retail functions on a high order commercial ribbon. The proper study and analysis of the distinctive arrangements of establishments by type over time will help to define more clearly the process of retail development in urban infrastructure study. The persistence of specific establishments (who) and functions (what) is of particular concern. The problem arises in how to effectively manage and display a multi-dimensional data set without comprimising the quality or integrity of the data.

The second observed problem viewed from a cartographic context is to define a process that allows the urban specialist easy and effective manipulative capabilities on the data set which will ultimately produce 3-D cartographic representations that reflect the multi-dimensional characteristics of the derived information. Combined with the recent advancements in technological capablilities, this process would present the 3-D cartographic object as an alternative approach for the effective management of urban spatial data. As noted earlier in Chapter I, solutions to the problems as defined would

Figure 3.2. System methodology approach.



Source: Adapted from Anderson and Starr (1984) clearly involve the interaction of computer graphics techniques, cartographic methods, and geographic analysis.

3.2.2 Hypothesis

The hypothesis derived proposes an integrative method for solving the problems as presented. This hypothesis proposes a procedural approach based on the three basic stages of data handling in cartography as defined by Robinson et al, 1978, P. 129-148.

The three stages have been applied to the unique characteristics of the data set and the technological tools to derive a stepped procedure. The first step of **data collection** involves capturing the raw data for the map and augmenting the data set with secondary data items to enhance the quality of the data base. This includes selecting the basic data items to be captured and the physical form in which it is to be maintained.

The second step of **data classification** involves the massaging and weeding of the data set to clean out inaccuracies. Since the data is from a variety of sources this will include any necessary steps required to bring the data set into a strict conformity. The most vital phase of this step is to encode the data items into a numerical hierarchial format. A clear understanding of the type of data available and the statistical measures required to manipulate it is necessary.

The third stage of the procedural approach involves the design and development of **application software**. Based loosely on the programmer's model of interactive graphics the software development step allows the conceptual interfacing of numerically encoded data to a graphic display mechanism. This step actually involves analytical processing of the encoded data by extracting data subsets and converting these to graphic representations.

This hypothesis presents the three stages of data handling as a method for solving the problems of observation and achieving the aims of the research.

3.3 Procedure

3.3.1 Data Collection

The data collection stage is the first step in the procedural approach Data collection involves the initial capturing of data items f om a primary source as well as the editing of the data set to create a clean format totally free of physical input errors.

For the Bond Street data set four sources were used. The study period decided upon before data collection was from from 1840 to 1980. Due to the mass of information available data items were collected at five year intervals beginning in 1840. It was believed that while greatly reducing the wealth of data to be captured, the time interval approach would allow for the collection of enough pertinent information to correctly reflect the retail changes that occured. The five year interval was defined with consideration of the geographic aims of researcn and the length of the study period. With such a breakdown 29 data subsets were collected covering the 140 year period.

In an effort to address the inherent errors that may be evident in a five year interval collection process, a secondary data set was also collected from 1950 to 1980 in one year intervals. This would allow for study at two levels of detail and perhaps lead to some future conclusions about data capture and the processes involved in temporal retailing studies.

The primary source for both data sets was the Post Office London Street Directory. Based on the information included in these annual directories, a data capture format was selected that would include the data item year, the postal street address, the proprieter/establishment name, and a land use/activity description. A format as such would allow for multiple sorting and cross referencing as well as data classification. For the initial interval of 1840 a similar, but more location specific source, Tallis's London Street Views was also used (Johnson, Baxter, 1986).

Two other important sources were used in the data collection phase. The third source of data was a field survey of ground floor activity on Bond Street undertaken in the summer of 1980. This survey served two purposes. It provided a check on the data listed in the more recent directories as well as providing a control point from which to identify ground floor activities. It is important to note that the primary directories did occasionally, but not consistantly, distinguish ground floor from upper floor uses. Urban retailing literature clearly indicates that retail functions exist primarily as a ground floor activity. Upper floor uses are generally reserved for more office and service oriented activities (Yeates, Garner, 1976). Consequently, as the aim of the research is slanted toward retail change, a subjective decision making process was undertaken to weed out first floor uses from upper floor uses. [20] At addresses where a clear distinction was not possible, all functions for that address were input and left for editing by the urban specialist.

The fourth source of data was the anecdotal and descriptive literature which refers to Bond Street. Being a high order retail street with a rich history Bond Street has a variety of literature pertaining to retailing over the study period. Much of this information was used to provide further evidence on the distinction of ground floor uses and specific address locations.

The original data base creation involved the manual input of all relevant source data into 80 byte fixed length sequential ASCII format computer files on the University of Alberta's MTS system. [21] This process of manual conversion required approximately 200 man hours to complete. Two data files were created, one each for the five and one year interval data.

Once the initial data entry process was completed several editing tasks were undertaken. These tasks would allow for the proper ordering, cleaning, validating, and updating of the data set by the urban specialists. [22] The secondary data sources were of primary importance here.

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[20] The weeding process was undertaken after discussion of the problem with Dr. Denis Johnson. Any subsequent indecisions were referred to him for review.

[21] The acronym ASCII refers to the American Standard Code for International Interchange. This is a standard set of 8-bit binary numbers used for presenting data in an alphabet, including punctuation ,numerals, and other symbols of text presentation and communications protocol.

[22] The *urban specialists* involved in this study are Dr. Denis Johnson and Mr. David Baxter.
Dr. Denis Johnson originally initiated the study on high order retailing on Bond Street and is currently involved in analytical research using the data set.
David Baxter is currently an urban planning consultant with the City of Vancouver. Mr. Baxter has undertaken numerous urban research initiatives throughout cities in Canada and shares a common interest in high order retailing with Dr. Johnson.

The major editing tasks undertaken were as follows :

1) Sorting of data files by ADDRESS first and then YEAR

2) Insertion of an asterik code for all known upper floor uses. This was initiated an address at a time.

3) Validating unique and peculiar occurences of establishments by researching secondary data sources particularly where spatial and/or temporal patterns appeared inappropriate (distinctly contrary to the hypothetical beliefs of the urban specialists).

4) Validating data items randomly by checking against the data source, particularly where upper floor functions were present.

5) Updating data items by modifying or adding yearly information where deemed appropriate. This included the addition of random upper floor uses that were left out.

6) Moving of all upper floor data items to separate files for future processing.

It is vital to understand at this point that the main subjective decisions concerning the establishment of the data base were made by the urban specialists with consideration of the cartographic and geographic aims of research. It was only with this approach that a consistent quality and integrity of the data set could be maintained and justified.

3.3.2 Data Classification - The Modified SIC

Data classification is a term that implies a generalization of data items in an effort to bring data into a strict conformity. If data is from a variety of sources one must equate the data items so they provide comparable values. Only through the comparison of relative values can meaningful information be generated and displayed from a data set. Robinson describes "classification as a standard intellectual process of generalization that seeks to sort phenomena into classes in order to bring relative order and simplicity out of the complexity of incomprehensible differences, inconsequential differences, or the unmanagable magnitudes of information." [23] Considering the qualitative nature of the data set this definition is quite appropriate.

[23] A. Robinson, R. Sale, J. Morrison (1976), P.152.

In order to facilitate the technology of the computer and incorporate the hypotheses in solving the defined problems, it was necessary to convert the data source descriptions of each land use activity into a standard numerical classification code that would incorporate the descriptive problems of dealing with temporal data, as well as embody the salient aspects of previous urban retail classification schemes. Previous literature on urban land classification identifies several important requirements necessary for a valid qualitative classification. Firstly, classification should be as universal as possible so that the same system could be used for several purposes and numerous data sets. Secondly, land uses should be classified hierarchially so that the same basic classification can be generalized to serve activities on different levels. This is particularly pertinent with respect to retail activity over time. Thirdly, classification should be as permanent as possible so that the results and/or activities at different dates could be compared.[14]

The classification scheme decided upon which would best fulfill the necessary requirements previously mentioned was a modified version of the 1980 Canadian Standard Industrial Classification (SIC). The modified coding system differs from the original SIC in two major areas. The first enhancement involved the increasing of sub-categories. To monitor the change in retailing over a period of time as long as 140 years, it was necessary to use a coding system that would reflect the change from local market retail activity (ie. fishmonger), to a high order fashion food retailer (ie. chocolatier) (Johnson, Baxter, 1986).

The second modification was to adjust for changes in the nature of retailing and the description of retail activity over time. For example, the further one goes back in time, the less clear the distinctions become between retailing, wholesaling, warehousing, and manufacturing.

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[14] A good introduction into commercial classification within urban areas can be found in :
M. Yeates, B. Garner, (1976), P.277-301.
A more recent discussion of land use classification can be found in :
P. Eichelberger, "Land Use and Space Use -- Data Standardization Issues in Data Base Management", in *URISA Annual Proceedings 1982*, 1982.
and in :
P.V. Virtanen, "Principles for the Classification of Land Use", in *FIG Commission 8: Urban Land Systems: Planning and Development, Proceedings of the FIG Congress*, Toronto, June 1986.

The enhancements to the SIC resulted in a 6 digit numerical code that is hierarchial in nature. With each digit an increased complexity in the level of description was incorporated. This method of classification allows for the temporal aspects of the activities to coexist. The modified SIC currently identifies 630 six-digit land uses at its smallest level of detail. These land use codes range from 000000 (vacant, non-economic, or missing), to 996200 (tour operators). The six-digit categories can be aggregated to five, four, three, two, or one digit levels for more generalization. There are 448 five-digit categories, 219 four-digit categories, 101 three-digit categories, 48 two-digit categories, and 10 one-digit categories. Further statistics on the classification scheme can be found in Appendix 2 accompanying the SIC code descriptions. Again it is of vital importance to note that the SIC used was defined only after a careful and somewhat lengthy validation and review period of the activities in the data set by the urban specialists. As well, the open ended design of the SIC has left room for further code subdivision and the inclusion of local and temporal unique uses which might be identified in the future (Eichelberger, 1982). While the hierarchial nature of the classification scheme lends itself to the multi-dimensionality of the data items, it also inherently increases the complexity involved in data manipulation and information generation. Consequently, a potential loss of data integrity is inherent to the classification process. The hierarchial nature of the scheme is an attempt to minimize data generalization and information loss.

In an attempt to continually minimize the margin of error existing in the classification process a regular review and updating of the SIC classes is required. This is especially important with the ongoing analysis of the data set as the urban specialists becomes more familiar with the data items and the processes that were involved in their development.

Once each data item was encoded and the two data files, one and five year interval, were reviewed to the satisfaction of the urban specialists each file was copied over to the Department of Geography's Intergraph based VAX 11 system. [25] An example

[25] Originally the coded data files were copied to a PDP 11/70 system resident on campus to which the Department of Geography had user access. Initial research was started on this system. However, shortly afterward the Department of Geography obtained it's own Intergraph based VAX 11-730 configuration. At this time all data was copied over to the new system and research initiatives

of the SIC hierarchy is presented in Figure 3.3 in the form of one data item. The modified SIC scheme is presented in Appendix 2.

3.3.3 Software Development

This stage in the procedural approach involves the design and development of application software based on expressed concerns and problems of the urban specialists. This stage is loosely based on the standard programmer's model of interactive graphics (Foley, Van Dam, 1982). However, in an effort to incorporate the functioning of a true spatial data information system the software developed must do more than merely convert numerically coded data into a graphic form. The generation of information from the data set is a vital component of information system processing. [26] "The critical function for any GIS is the integration of data." [27] Intermediary processing steps are involved before the graphic processing routines are to be developed. The conceptual framework on which the application software is based is presented in Figure 3.4.

The application software was developed around 3 primary areas of initial inquiry that were of concern to the urban specialists. These were :

i) the identification of relationships between specific activities throughout time at specific locations

ii) the average length of stay of all activities at specific locations

iii) the persistence of activity types at selected locations throughout time

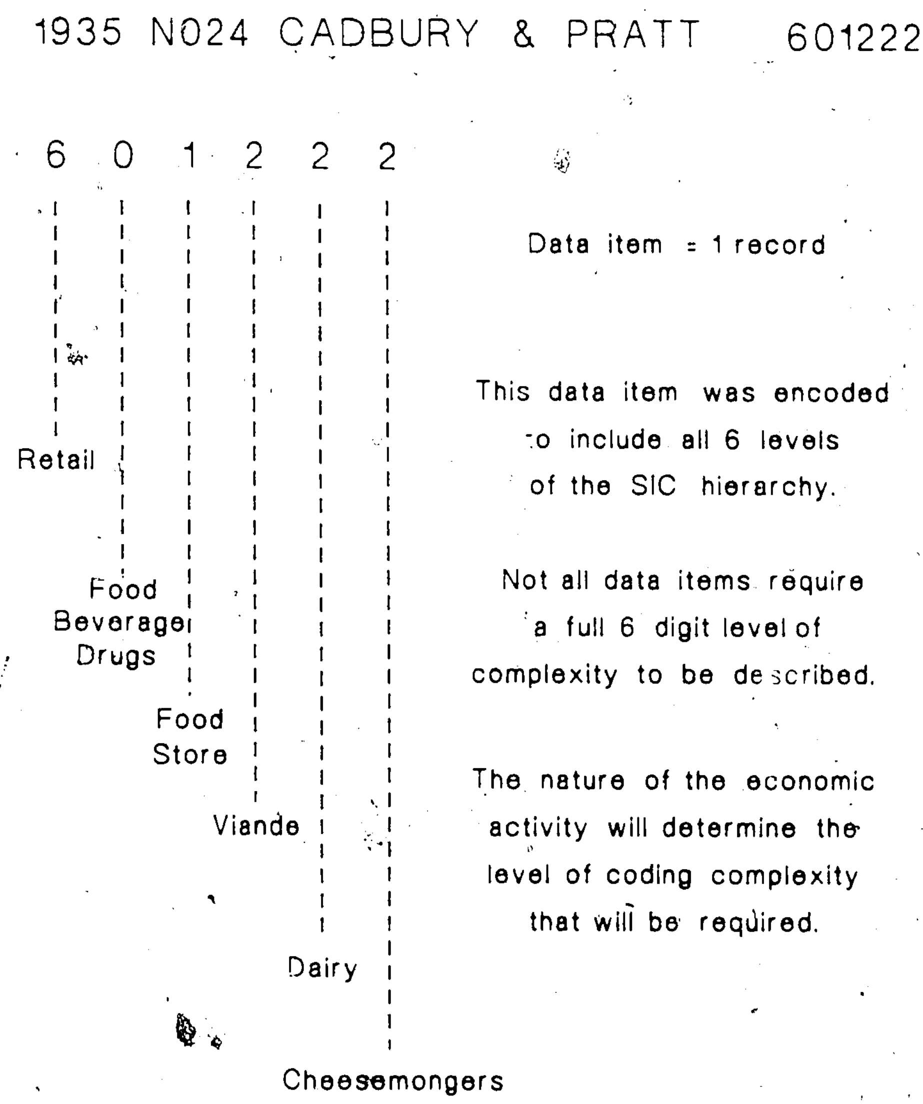
The data processing software, components three and four of the GIS model, were written in the FORTRAN 77 programming language on the Virtual Memory System (VMS) operating system of an Intergraph based VAX 11-730 system configuration. Current graphic interface routines make use of Design File Processor Interface (DFPI) subroutines provided by Intergraph in their standard graphics system. These subroutines

[25](cont'd) were reviewed with consideration of the updated capabilities. Eventually this necessitated complete rewriting of all software.

[26] The notion of what is involved in a true GIS is presented in Chapter I. Specific reference is made of the necessary components (3 and 4) as defined by Marble.

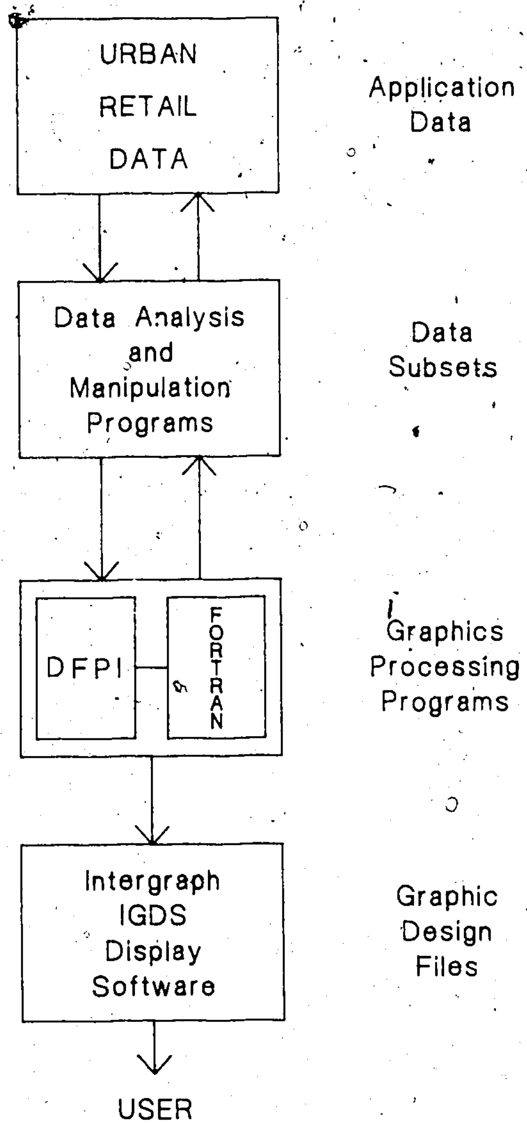
[27] K. Anderson; L. Starr, "Geographic Information Systems", in *South African Journal of Photogrammetry, Remote Sensing, and Cartography*, Volume 14, June 1984, P.8.

Figure 3.3. A sample encoded data item.



Source: Data - Bond St. 5 year interval data set
Modified SIC by D. Johnson, D. Baxter (1984)

Figure 3.4. Conceptual framework of software development.



Source: Adapted from Foley and Van Dam (1982).

allow the creation of simple graphic elements in the Intergraph graphic file format by merely passing element coordinates (X,Y,Z) and display parameters as subroutine arguments. The parameters that describe the element are left entirely for the programmer/user to define. Once the Intergraph format graphic file is created with the elements defined by the user it can be interactively viewed and edited using the Interactive Graphic Design System (IGDS) software provided by Intergraph. A complete overview of the VAX/VMS * Intergraph interface is presented in Chapter IV. A complete overview of the Urban Mapping Information System (UMIS) application software is given in Chapter V.

4. TECHNOLOGICAL TOOLS

4.1 Interactive Computer Graphic Processing Concepts

Perhaps the greatest development in the computer processing industry over the past decade has been the development of interactive computer graphics. The advancement of computer graphic processing techniques has proliferated the application of automated procedures into a wide variety of disciplines. "Interactive computer graphics is the most important mechanized means of producing and reproducing pictures since the invention of photography and television." [21] Interactive graphics may be defined as a form of man-machine interaction which combines the best features of textual communication and human decision making, with the graphical representation of specific data. The management of geographic data is a primary area of application.

The integration of computer graphic techniques into the mapping realm was initially perceived in a negative fashion by the cartographic community. The requirement for comprimising cartographic standards and aesthetic values for the sake of automation was not well accepted. However, with the rapid increases made in computer graphic technology and user oriented application software over the past several years, interactive computer graphic techniques have helped forge cartography as a scientific discipline. Map making is no longer perceived simply as an art, but has come to be characterized by it's methodical application of computer graphic techniques.

The application of an interactive computer graphics system requires a basic understanding of the processing concepts involved when using cartographic data and methods. Perhaps the concept of greatest importance is **interactive mapping**. Interactive mapping, as discussed in Chapter I, implies a real time interaction between the cartographer, or data specialist, and the computer. Vital subjective decisions can be made while viewing the cartographic image. More importantly, cartographic parameters can be altered through easy communication with the machine. The notion of interactive map editing is of prime concern.

[21] J. Foley, A. Van Dam, *Fundamentals of Interactive Computer Graphics* (Addison Wesley Pub. Co.:Toronto.1982), P. 5.

Another processing consideration that is peculiar to computer graphic techniques is the **virtual map**. Also discussed in earlier chapters, the virtual map is characterized by its lack of permanent tangibility. A map as such is created, viewed, and edited through interactive computer graphic hardware and software. A traditional hardcopy map product is only available through software interfaces to sophisticated plotting devices. A variety of these interfaces are available and common in map production environments. However, it should be noted that the hardcopy map is only a secondary product of the computer graphic technology. The virtual map is of primary importance. The power of interactive computer graphics lies in the use of virtual maps as a flexible analyical tool in geographic research and applications (Moellering, 1983).

A concept of supreme importance when dealing with an interactive computer map is **scale independence**. Traditionally, the definition of map scale has been a necessity in cartography. "Digital representation of cartographic information creates an illusion of independence from scale. With traditional map products, the graphic medium imposed physical bounds on scale. There is no similar factor in digital cartography."[29] Technological capabilities afford most computer graphics systems the ability to view or orientate a map image at any scale the map reader desires. The ability to zoom in/out to view a specific area of a map is an inherent advantage of computer graphics techniques. In the computer graphics environment the term 'map scale' refers to the finest level of accuracy that is valid for the use of a cartographic data set. To achieve optimum use of any cartographic data set an understanding of the accuracy for that data set is required. This is essential in topographic mapping applications where positional (geographic) accuracy is most significant. In thematic applications, where the relative positioning of cartographic features is often more important, the dependencies on map scale are less rigid. In either application, the acknowledgement and understanding of an 'accuracy label' for the digital map image is highly desirable. None the less the ability to deal with cartographic data independent of scale is an inherent advantage that allows computer graphic technology to be used for analytical purposes. The notion of scale independence is important when considering the concept of visual analysis as presented in Chapter I.

[29] N. Chrisman, "Epsilon Filtering : A Technique for Automatic Scale Changing", in *Technical Papers of ACSM-ASP, 43rd Annual Meeting,* 1983, P. 322.

Another concept that is directly dependent on computer graphic technology is **dynamic processing**. This concept is very important in the use of the modern 3-D cartographic image. Dynamic processing is discussed earlier in reference to Moellering's identification of dynamic and static maps. "While static pictures are often a good means of communicating information, dynamically varying pictures are frequently even better. This is especially true when one needs to visualize time-varying phenomena, both real and abstract." [30] Foley and Van Dam explain dynamic processing as **motion dynamics** and **update dynamics** (Foley, Van Dam, 1982). The definition of this concept closely parallels Moellering's surface exploration and spatial temporal display. Motion dynamics allows the user to view the map image from a variety of locations or orientations in the image area. Commonly, the map object remains stationary and the viewer moves around it, panning to select the portion of view and zooming in and out for more or less detail. "Update dynamics refers to the actual change in shape, color, symbolization, or other properties of the (map) object being viewed. The smoother the change, the more realistic and meaningful the result." [31] The understanding and consideration of this concept is especially pertinent in light of the research objectives of the case study identified in Chapter III.

The development of any system for the cartographic application of spatial data using interactive computer graphics requires the integration of all the concepts discussed. No approach that perceives using interactive computer graphics as a technological tool can ignore these concepts. With careful understanding and appropriate system development methodologies, concepts as such can become powerful mechanisms for efficient spatial analysis.

Ultimately the use of any computer graphics system will necessitate software development if specific applications are required. The development of application software must revolve around intrinsic considerations of the computer operating system. This includes both hardware and software characteristics. With the conceptual considerations of using an interactive computer graphics system in mind, it is now appropriate to review the technological tools that were used in this application study.

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[30] J. Foley, A. Van Dam (1982), P. 5.
[31] J. Foley, A. Van Dam (1982), P. 6.

4.2 The VAX/VMS * Intergraph Interface

The purpose of this chapter is twofold. First, as reviewed in the preceding section, it is to familiarize the reader with the conceptual considerations of using an interactive computer graphics system for processing geographic data. Secondly, it is to identify, and describe to the reader the technological tools that were utilized in this research.

The technological tools used consist of an integrated configuration of hardware and software developed by Intergraph Corporation. The interactive computer graphics system is discussed from three viewpoints. These are the VAX/VMS operating system, the graphics system interface, and the application software interface.

4.2.1 VAX/VMS System Overview

A brief overview of the VAX 11 system is required before the specifics of the operating system are discussed. [32]. The basis of the Intergraph computer graphics system is the VAX 11 computer. VAX 11 is a family of high performance 32-bit mini-computers that share a common *architecture*. This VAX 11 architecture evolved from the popular PDP 11 series of mini-computers developed by Digital Equipment Corporation (DEC). The major advantage of the VAX 11 series is its extended 32-bit *virtual address space*. The acronym **VAX** refers to **V**irtual **A**ddress **EX**tension. With 32 address bits, the VAX 11 virtual address space is approximately 4.3 billion *bytes* (2**32). "This huge virtual address space allows VAX 11 computers to accommodate very large programs and large arrays of data." [33] The concept of virtual address space is best explained in the context of the VAX/VMS operating system.

As well as a common architecture, the VAX 11 series of computers also use the same virtual memory system called VAX/VMS. The acronym VAX is commonly used to refer to the hardware portion of the system, while VMS refers to the software components. **VMS** is an abbreviation for **V**irtual **M**emory **S**ystem. "In this case, the operating system schedules work to be run on the system, supervises and coordinates

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[32] The introduction of numerous computing terms in this chapter necessitates the use of Appendix 1 for full explanations. Terms that are defined in Appendix 1 are identified by the use of italics.

[33] *VAX 11 Concepts - Architecture and Machine Overview* , Digital Equipment Corporation, Bedford, Mass., P. 7-9.

all system activities, and manages the efficient use of *physical memory*." [34] In a virtual memory system such as VAX/VMS there are two distinct types of addresses, virtual and physical. A *physical address* is an address that is recognized in *main memory*. In other words, it refers to real storage locations in memory. A *virtual address*, on the other hand, is an address generated by an executing program, whenever a specific instruction or item of data is referenced. For example, when a program is executing in the *central processor unit*, hereafter CPU, only a very small portion of the program actually resides in physical memory at any one time. During the program execution *pages* are continually moved in and out of physical memory by the VAX/VMS operating system. Pages that are actively being referenced are placed in physical memory, while inactive pages are held in *auxilliary storage* until they are needed. In this way, auxilliary storage serves as an extension of physical memory so that, from the programmer's viewpoint, physical memory appears to have a 'virtually' unlimited storage capacity. The concept of a virtual memory system is illustrated in Figure 4.1.

A concept that is dependent on virtual memory is *multiprogramming*. VMS exists as a priority based multiprogramming system. Multiprogramming refers to the fact that since the operating system is continually *swapping* pages of a program in and out of memory, more than one program can be executing at a time. "Hence, the power of the CPU is better utilized and this usually results in greater memory efficiency." [35]

In view of the multiprogramming approach, one other item requires discussion. The term *program* has been used as if there is an implied understanding. To clear up any possible descrepancies a definition is required. In the context of VAX/VMS a program is a logical sequence of instructions written in a computer language (ie. FORTRAN), that tells the computer how to solve a specific problem. The source program must be translated into *machine code* through the use of a *language compiler* and *linker* to become a machine *executable image*. It is this machine executable image that is *run* on the operating system. The process of program compilation and linking is presented in Figure 4.2.

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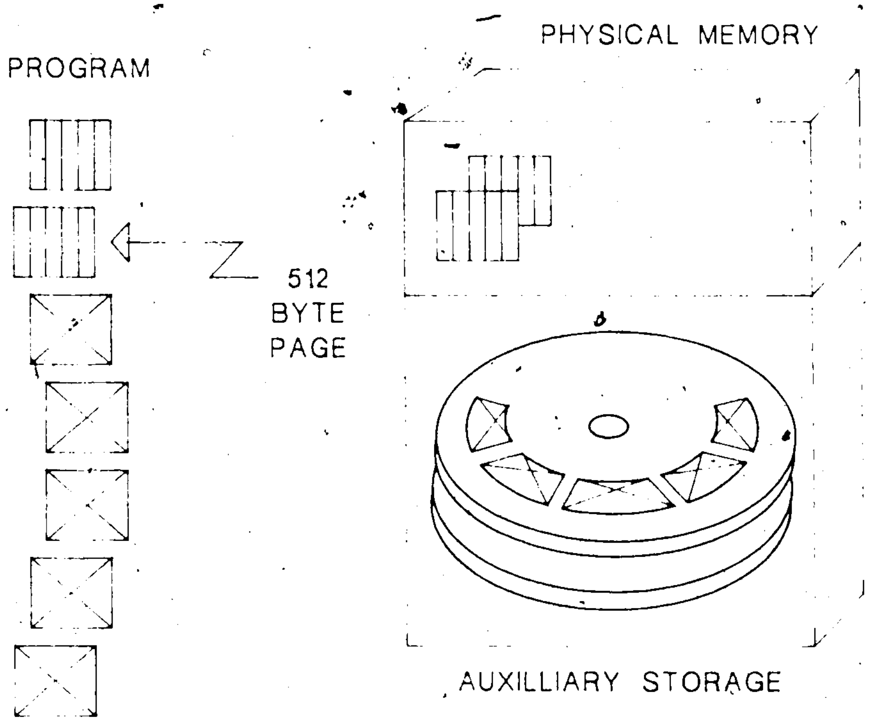
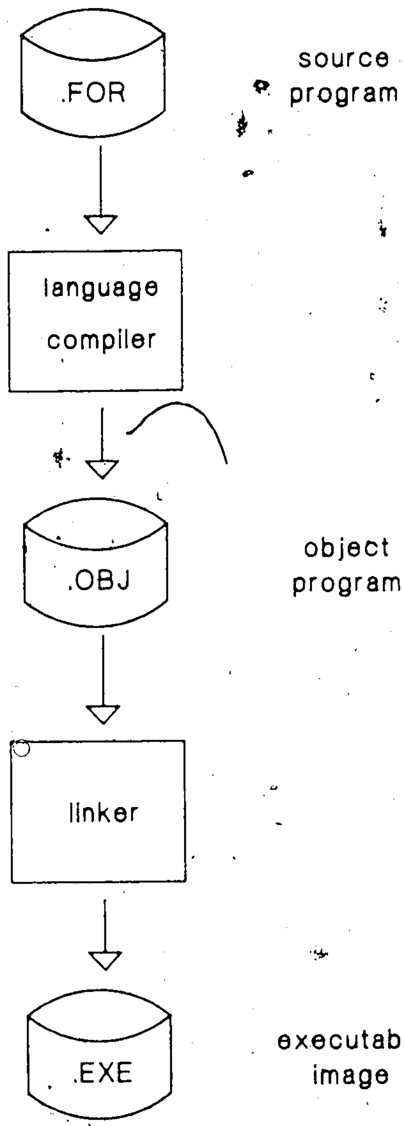
[34] *VAX 11 Concepts - Architecture and Machine Overview*, P. 7.
[35] *VAX 11 Concepts - Operating System Overview* , Digital Equipment Corporation, Bedford, Mass., P. 1.

Figure 4.1. The VAX/VMS virtual memory system.



Source: Modified from :
VAX 11 Concepts - Architecture and Machine Overview, P. 8, Digital Equipment Corp., Jan. 1983.

Figure 4.2. Program compilation and linking.



Source: Adapted from VAX 11 Concepts -
Operating System Overview, P. 8. January 1983.

Due to the overwhelming nature of discussing the VAX/VMS system, and the introduction of a wide variety of terms that relate to it, a brief summarization is appropriate.

"Virtual memory is a sophisticated and powerful technique of *memory management* in which main memory and auxilliary storage are combined to give the illusion of vast amounts of main memory available to the programmer." [36] The main idea behind virtual storage is that the operating system takes care of the many details of memory management for the programmer. "The programmer works in a symbolic, virtual address space of tremendous size and the system is responsible for determining what hardware location each symbolic address is intended to reference." [37]

Several notable advantages of using a virtual memory system can be identified. General memory efficiency occurs in that large images (programs) are easily handled without the need for overlays. The necessity for using *program overlays* is a problem that has plagued many graphic applications of the past. This is especially important in light of the application software that has been developed for this research. A secondary advantage that results in memory efficiency is that the use of fixed size pages inhibits fragmentation of memory. It should be noted here that the use of 1 page (512 bytes) is a standard unit used by Intergraph in the formatting of their graphic files (1 block = 512 bytes).

A second major advantage refers to individual *process* protection. Individual user processes for each *log on* allows unique address spaces to be used. Accordingly, no process can affect the memory area used by another process. Processes are protected from one another. This is an important point when considering the application software developed for this research. For example, two individual users could log on to the same *account* and execute the same module of the application software, as long as they are utilizing different data sets. Each user would be considered unique. The third main advantage of a virtual memory system is that the large quantities of virtual memory allow for many processes to occur simultaneously.

This brief overview of the VAX operating system provides a framework with which to examine Intergraph's configuration. Many of the system development

[36] *VAX 11 Concepts - Operating System Overview*, P. 41.
[37] *VAX 11 Concepts - Operating System Overview*, P. 41.

methodologies used by Intergraph no doubt revolve around the VAX hardware architecture and the VAX/VMS operating system.

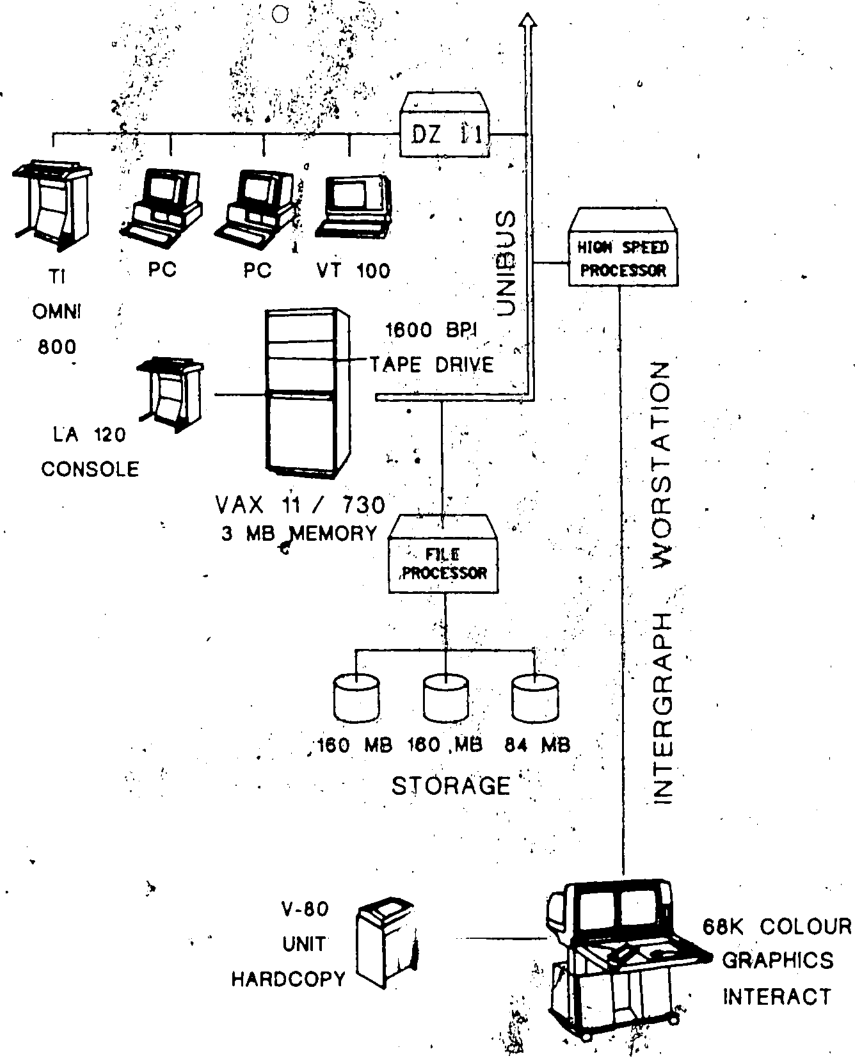
4.2.2 Intergraph System Overview

The interactive computer graphics system employed in this study is an integrated configuration of hardware and software developed by Intergraph Corporation. Since it's founding in 1969 Intergraph has been manufacturing computer graphics systems to meet the needs of a broad spectrum of engineering, mapping, and scientific applications. Intergraph is currently the leading supplier of turnkey graphic systems in Canada. Recent figures indicate that approximately 60 % of Intergraph's market share is in mapping applications. With a base of 152 systems installed in Canada alone, Intergraph has become an industry standard in the map production field. [31] This acceptance of Intergraph is not without its questions and criticisms though. Intergraph is not well accepted by the cartographic community as being a complete cartographic system or geographic information system. Little has been done on cartographic and geographic applications that go beyond the bounds of traditional cartographic research initiatives. Thematic research is required to address many of the pertinent themes of study in cartography. The use of thematic 3-D maps is a prime example. This research is one such effort to apply and evaluate a computer graphics system as a 3-D mapping tool for the management of thematic spatial data.

In the summer of 1982 the Department of Geography at the University of Alberta purchased an Intergraph workstation in an effort to address many of these academic studies. The acquisition of a turnkey computer graphics system was initially perceived as a teaching tool for the department. However, upon familiarization with the system it became evident the power of the Intergraph system was in it's function as a research tool. In September of 1984 the Department of Geography obtained a complete VAX 11-730 based Intergraph configuration. Since that time several cartographic research projects have been initiated. A system diagram for the Department of Geography's computer graphics configuration is presented in Figure 4.3.

[31] These figures were obtained at the 1986 Canadian Intergraph Users Group (CIUG) Annual Conference held in Calgary, Alberta, September 8-10, 1986.

Figure 4.3. Department of Geography
VAX 11-730 System Configuration



Source : D. Buckley, Dept. of Geog.
University of Alberta

A complete overview of the Intergraph system used for this research requires a discussion of both hardware and software characteristics. A brief review of the hardware features is appropriate a this time.

Hardware Considerations

Intergrap employs the VAX 11 series of mini-computers as the data processing foundation for it's graphics stations. The VAX line represents the industry standard for performance and reliability throughout the scientific and engineering communities. To help balance the extensive processing load associated with interactive computer graphics functions Intergraph has enhanced the VAX hardware with a series of specialized processors. These specialized hardware processors include The File Processor and the High Speed Communications Processor. [39]

The File Processor is an integral component of all Intergraph data processing systems. It is a combined storage module disk controller and scanner. As a disk controller, this processor supports standard disk reads and writes for the host operating system. As a scanner, this processor performs data pre-processing, during reads, and passes to the host computer only the data that meets scan criteria specified by the graphic software. The purpose of the device is to reduce the amount of data that must be processed by the host computer in support of the graphic terminals, thereby making the performance more responsive. This is perhaps the most important hardware enhancement Intergraph has made to the VAX.

The High Speed Communications Processor manages local and remote communications between the CPU, graphic workstation, and the plotter. In the case of the VAX 11-730 system used for this research no plotters were available. As well as the two main enhancements made to the VAX line, Intergraph also provides three other hardware specific devices. These are a magnetic tape drive, disk drives, and a variety of hardcopy devices.

The magnetic tape drive is a device that allows online communication with the CPU to transfer data from the magnetic tape medium to disk, and vice versa. Its portability and use as an inexpensive archival method are its main advantages. The tape

[39] The File Processor is a registered trademark of Intergraph Corporation.

drive unit of the VAX 11-730 is located in one physical configuration with the CPU.

The disk drives provided can be either online fixed or removable-media disk devices with storage capacities that range from 80 megabytes to 675 megabytes per disk. The disk drives are, outside of the CPU, the most important devices in the system. Ultimately all data is stored and accessed on these disk devices.

The hardcopy devices provided by Intergraph may include an electrostatic plotter with a banded vector-to-raster convertor (BVRC), a pen plotter, printers, and V-80 electrostatic hardcopy unit. The only hardcopy device attached to the VAX 11-730 system is a V-80 hardcopy unit.

In conjunction with the storage and communication devices mentioned, Intergraph systems also include a full range of hardware devices oriented towards the manipulation of graphic data. A high performance graphics workstation is the key item.

The Intergraph *graphics workstation* includes dual 19 inch screens that display a consistent, sharply delineated raster image with a 1280 by 1024 *pixel* addressibility and resolution. One screen is monochromatic and the other colour. The *ergonomic* features of the workstation allow the user to adjust screen positioning along with brightness and contrast of the individual screens. Although both screens use the same graphic design file, they maintain independent sets of window control parameters to permit the simultaneous display of different window views of the graphics file. Up to four window views can be simultaneously presented on each display screen. The colour screen can display up to 256 active colours from a palette of over 16 million.

The workstation also includes a hinged input table with a sensitized worksurface area measuring 56 cm by 86 cm (22" by 34"). This is commonly referred to as the *digitizing table*. Three other hardware devices are connected to the workstation and commonly located on the digitizing table. These are the floating menu, the cursor, and the alphanumeric keyboard.

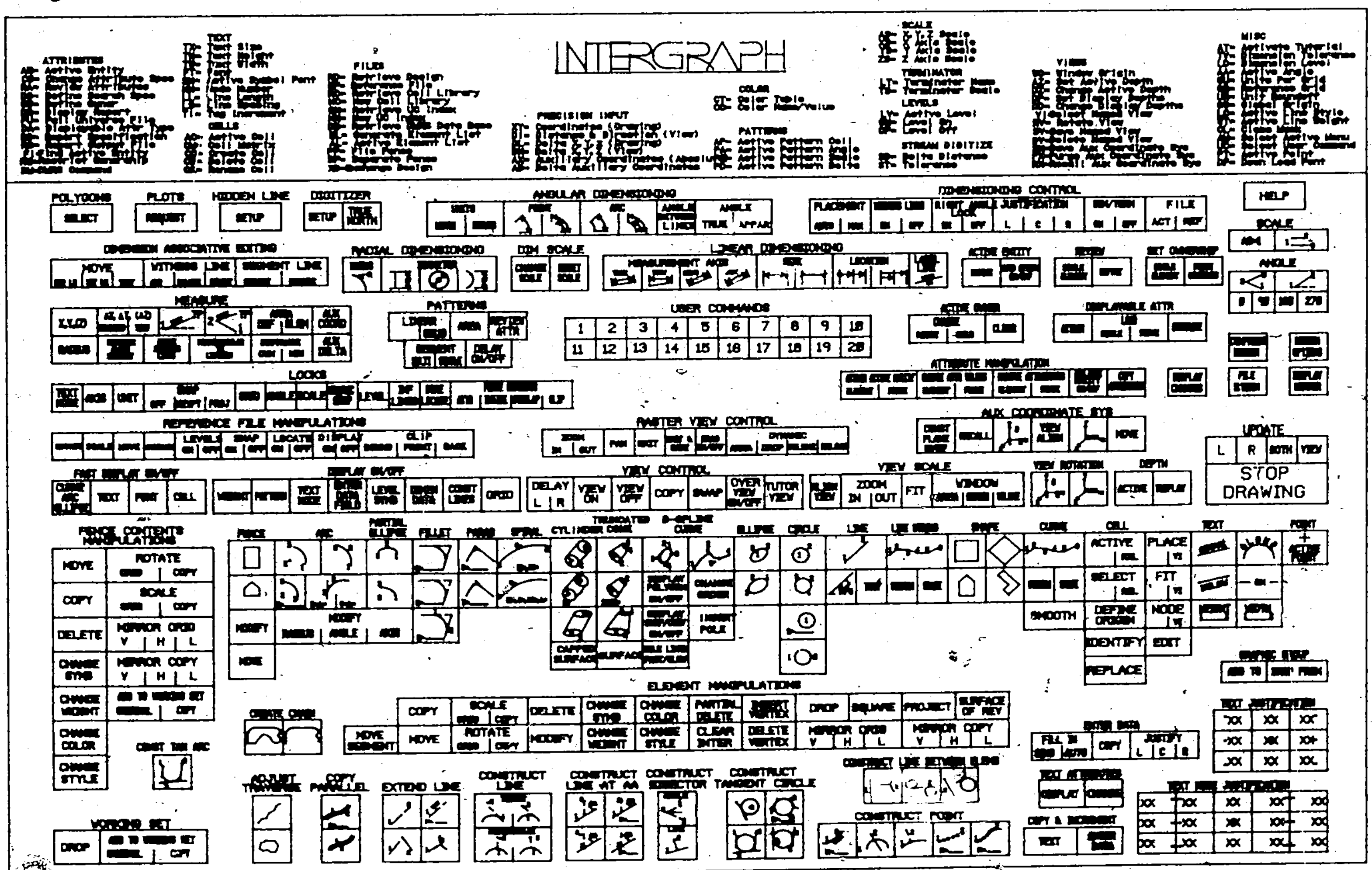
The *floating menu* is a command menu placed in a special tablet that is attached to the digitizing table via a cable. The menu can be moved around the table during a graphics session without having to reconnect or reload the commands. If required the *command menu* can be removed from the tablet and inserted beneath the digitizing table surface cover, making the floating menu dispensable. The command menu is a hardcopy paper graphic that displays all the editing commands available to the user during a graphics session. It is divided into two sections. The upper section of the menu contains a list of textual key-ins and their meanings. They are further subdivided into groups by their function. This section of the menu is inactive, meaning that the key-in listing is a memory aid only. All key-ins are entered via the alphanumeric keyboard.

The lower section of the command menu contains the graphic software command set. These command boxes are also grouped by function. The lower half of the commands consist of placement commands for graphic elements. The upper half consists of controls, locks, and manipulations. In a graphic design session all commands are chosen by the user placing the hand held cursor crosshair over the selected command box and pressing the *command button* (C). The command menu is only operational when a user is interactively viewing a graphic design file. The graphic command menu is illustrated in Figure 4.4.

The second hardware device attached to the digitizing table is the *cursor*. The cursor can be referred to in two ways. The first mode of operation of the cursor is as a hand held device that contains a crosshair for selecting commands on the menu and specifying the position of points on a drawing to be digitized. The second mode of operation is as a movable cross on the viewing screen which corresponds to the crosshair on the hand held cursor. As the hand held cursor is moved, there is a corresponding movement by the cross on the screen. The mode of operation of the cursor is dependent on the buttons depressed on the top of the cursor. There are 12 buttons on the regular hand held cursor. The top three buttons allow the user to select commands from the menu, select data points in the graphics file, and reset/reject any previous selection. The second row of buttons are for selective functions such as *snapping* to an exact element or vertice. The final two rows of buttons are reserved for user defined functions. If the graphics terminal is of the 68000 based high performance type, these buttons are reserved for the dynamic manipulation of the terminal data set. This function is discussed later in this chapter.

The last hardware component attached to the graphics workstation is the *alphanumeric keyboard*. The keyboard allows the user to interactively communicate with the computer via textual commands. All the functions of a regular keyboard are included

Figure 4.4. The IGDS command menu.



Source : Modified from IGDS User Guide 8.8, Page 1-9. Intergraph Corp.

as well as some special keys that can be used in conjunction with the graphics software.[40]

Perhaps the most important hardware capability of the graphics workstation is the *terminal data set*. This feature is available on Intergraph's 68000 series terminals. It allows the interactive user to download a graphic file into the terminal. Once the the graphic file has been loaded into the terminal the system CPU is freed for other manipulations. Operations such as dynamic pan, zoom, and rotation may be accomplished locally with the 68000 micro-processor performing the update operations at a high rate of speed. With respect to a 3-D graphic file, a dynamic volume would be loaded into the terminal data set. The advantages of dynamically panning, zooming, and especially rotating a 3-D image in real time, addresses many of the traditional problems associated with 3-D maps. Defining viewing azimuth and elevation angle becomes an easy operation that is performed interactively by the map user. Many of the inherent problems that relate to map clarity and surface blockage are no longer of concern. The map in this sense is viewed as a dynamic 3-D image without the limitations of a finite viewpoint or orientation. The use of the dynamic map requires a basic understanding of the concepts of motion and update dynamics discussed by Foley and Van Dam, as well as Moellering's notion of dynamic and static maps.

Software Considerations

Now that the hardware configuration has been identified, it is suitable to review the software foundation of Intergraph's graphics system. Two major software packages form the operating nucleus of the Intergraph computer graphics system. These are the Interactive Graphics Design Software, hereafter IGDS, and the Data Management and Retrieval System (DMRS). Due to a variety of considerations this research only necessitated the use of IGDS. [41] The role of IGDS as Intergraph's nucleus software is

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[40] A full explanation of these special keyboard capabilities can be found in the *IGDS Users Guide Version 8.8*, Pages 1-16 to 1-17.

[41] Initial investigations into the use of DMRS for this research included prototyping several database structures for the storage and manipulation of the data set. However, upon testing it was decided that the use of DMRS would involve too many operating overheads, in terms of disk storage and processing requirements, without yielding sufficient benefits that would be directly applicable to the objectives of the research.

illustrated in Figure 4.5

IGDS is a general graphics software package that provides a full set of pre-programmed design and drafting tools (commands) for all disciplines. It supports a comprehensive 2-D and 3-D capability with a primary emphasis on ease of use and user friendliness. The software features a 32 bit database, based on the VAX/VMS *Files 11* file structure, with more than 4 billion addressable points of resolution per dimension in a 3-D design cube. The size of the database structure allows massive designs and maps to be constructed with extreme precision.

Currently the IGDS environment (ICE) contains 4 modes of operation. [42] These are *GRAPHICS, UTILITIES, HELP,* and *DCL.* Any of these modes can be traversed by another. A brief description of each mode is fitting.

GRAPHICS is the primary mode of operation within IGDS and is used for the viewing and editing of a graphics design file. The characteristics of this mode of operation and an explanation of the graphic design file parameters follows the description of the IGDS subsystems.

The UTILITIES mode is used for the creation of new design files and file management functions. External operations can be initiated to copy, delete, rename, merge, compress, reduce, or create graphic design files.

DCL is commonly the third mode of operation within IGDS. It allows users access to the VAX/VMS operating system via the Digital Command Language (DCL). DCL is the operating system language that allows users to perform functions and file manipulations through a command driven process. DCL is discussed in the application software section of this chapter.

The last mode of operation in IGDS is an online HELP facility. This help function provides useful information to the user about the IGDS environment. The four major subsystems of IGDS are illustrated in Figure 4.6

Having introduced the modes of operation within the IGDS environment it is now appropriate to discuss the GRAPHICS subsystem and the operational characteristics that pertain to the 3-D graphics file format.

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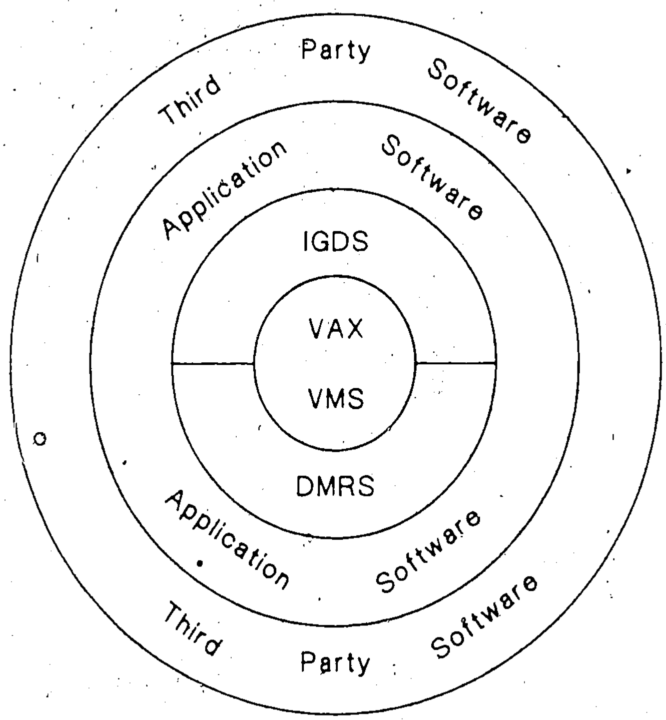
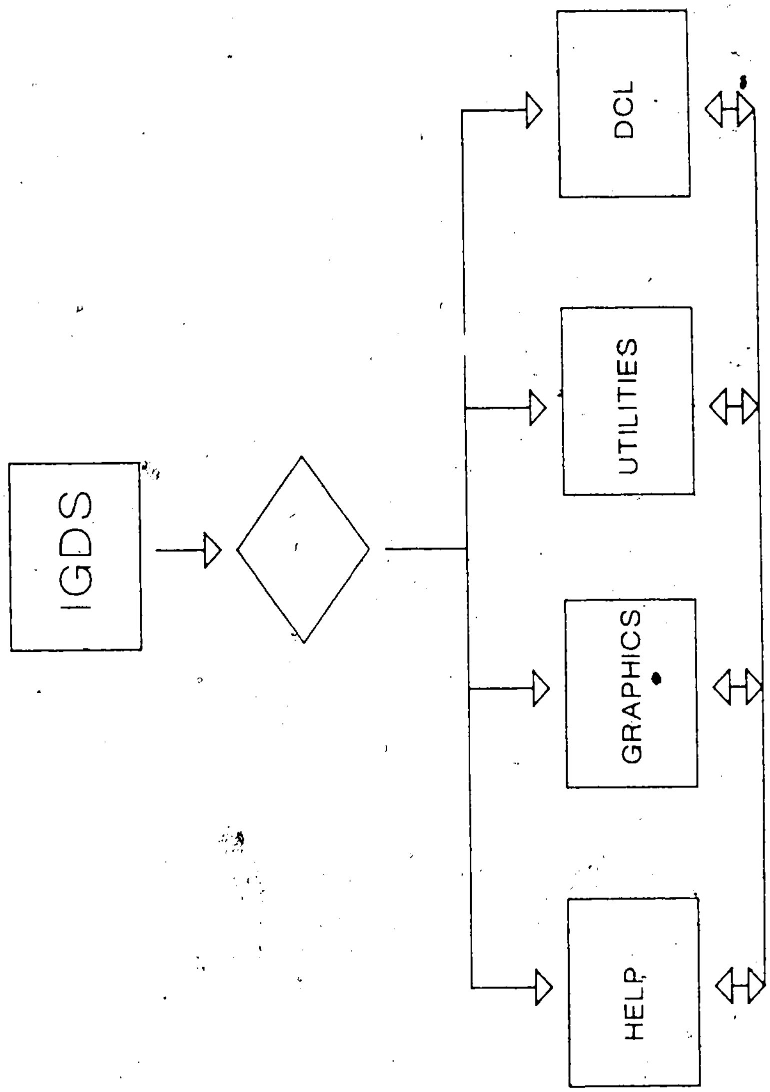
[42] ICE refers to the Intergraph Command Environment.

Figure 4.5. The configuration of the Intergraph nucleus software.



Source: Modified from :
IGDS Users Guide, P. 1-2.
Intergraph Corporation. January 1985.

Figure 4.6. The subsystems of IGDS.



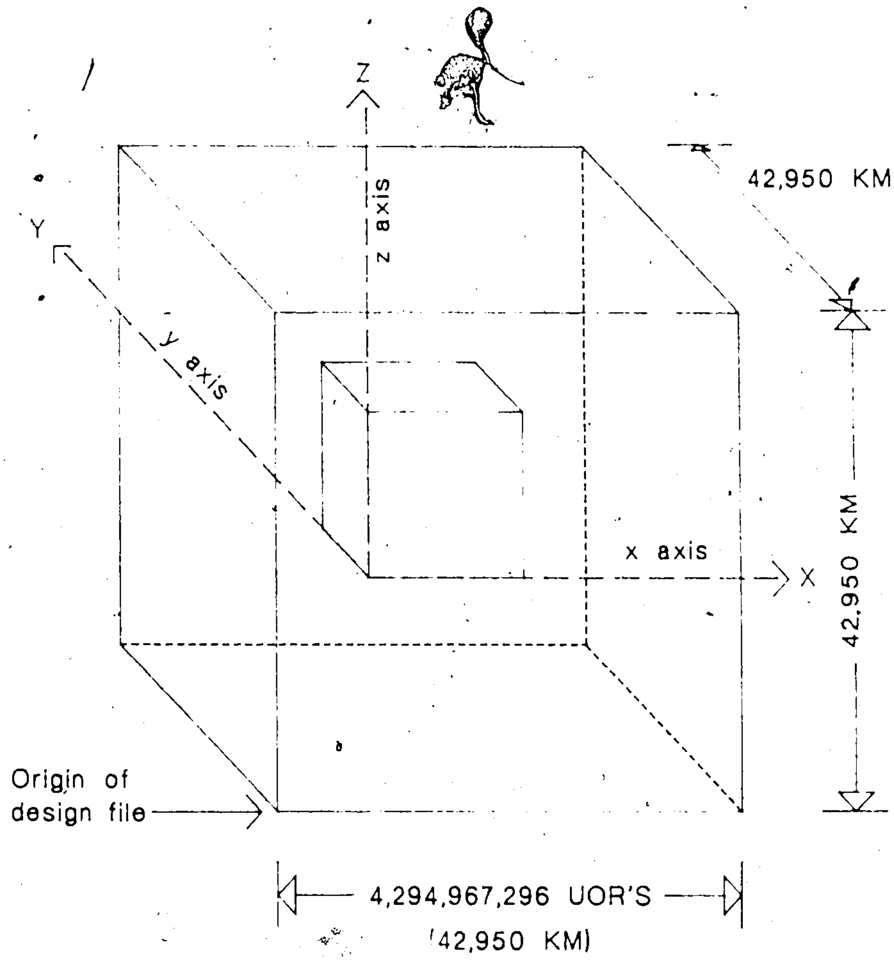
Two distinct graphic files can be created for the GRAPHICS mode of operation. These are *design files* and *cell files*. Design files require the most detailed description.

Once a design file has been created in the UTILITIES mode it is 'entered' in GRAPHICS mode. At that time an understanding of the design file setup is required. The item of primary importance in any design file is the *working unit* definition. The establishment of working units in a design file is analagous to the definition of a system of unit measurement (ie. metric). Each 3-D design area is a cube with 4,294,967,296 (2**32) units of resolution, hereafter UOR's, along each dimension. The UOR represents the finest degree of accuracy at which a point can be located within the design area. The definition of working units allows the user to relate the internal measurement of UOR's to real world coordinates. Thus, the proportional placement of graphic elements in a real world coordinate system is possible. The positional accuracy of all elements is maintained. The standard format for defining working units is by identifying the system of measurement and the factors involved. This is accomplished by distinguishing a master unit, a sub unit, and a positional unit factor. In Intergraph notation this is MU:SU:PU. The positional unit indicates the finest degree of accuracy for the design. The working units defined for the case study base map were 1 KM: 1000 M: 100 CM. The finest unit of accuracy for the base map is 1 centimetre (cm). The concept of working units in the 3-D design area is illustrated in Figure 4.7.

The next design file parameter of vital importance is the *level*. For ease in analyzing, editing, and integrating complex maps, IGDS allows the user to create and store map elements on 63 identically sized overlays within the design area. These overlays are referred to as levels. In a 2-D design area each overlay is a plane. In the 3-D design area each overlay is a cube. Levels can be displayed, edited, and plotted in any combination. Simple textual commands entered on the alphanumeric keyboard allow the user to turn off *(OF=)* or turn on *(ON=)* levels of choice. The flexibility of representing data on multi-levels, particularly with a complex 3-D object, is an advantage that affords greater possibilities when considering visual analysis and map clarity.

While levels exist as the primary distinguishing parameter between graphic elements, others are available to help further delineate features. The other pertinent parameters include *line weight, line code, element colour,* and *font, text height,* and

Figure 4.7. Working unit definition in the 3-D design file.



Working Unit Definition : 1 KM (MU)
1000 M/KM (SU)
100 CM/M (PU)

Source : Adapted from IGDS Users Guide, P. 1-22. Intergraph Corporation. January 1985.

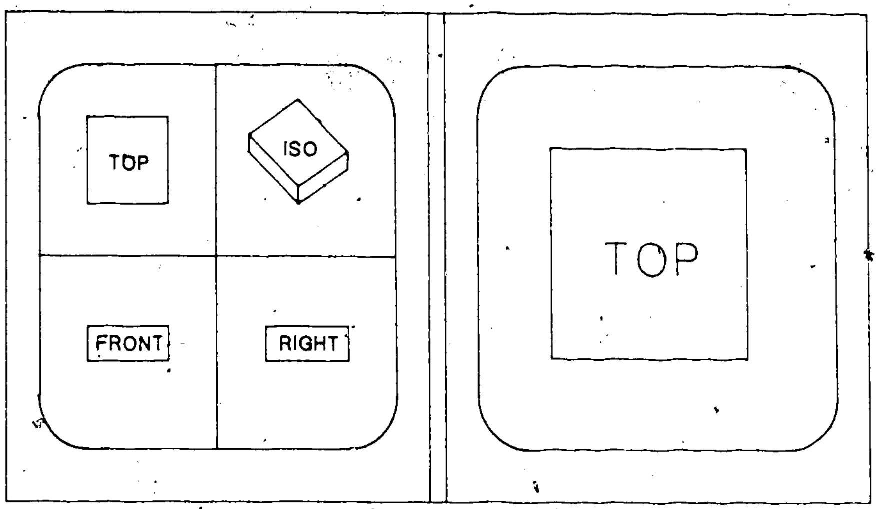
text width for text placement. The combination of these criteria allows users to easily distinguish features on a map.

One other characteristic of 3-D graphic design files requires an understanding at this time. As previously mentioned each screen can afford the user 4 views. In a 3-D graphic design file each view must be defined from a planar viewpoint. The standard view setup used in this research represents the graphic image in 4 views on the left screen. These orthogonal views enable the user to see the top, front, right side, and an isometric view of the graphic design. Other view setups are possible. The right screen presents only 1 view in a top orientation. While it appears you are working in a 3-D file; in actuality planar input techniques are used to create 3-D designs. This setup is illustrated in Figure 4.8. Each view (orientation) can be manipulated individually. A wide variety of manipulations is available for the views. These range from independent view rotations to volumetric display windows. The use of the terminal data set to dynamically manoeuvre the 3-D map is only available on one screen, the right by default. Full editing functions are permitted while the design is dynamically loaded.

The second type of graphic file distinctive to the GRAPHICS subsystem is the cell file. This is commonly referred to as the *cell library*. Cell files exist as standard retrievable libraries of graphically defined symbols generated by the user. The symbols, or *cells*, stored in a library are retrieved by a naming convention for placement in the active design file. The only requirement is that 3-D design files only use 3-D cell libraries. The ability to create a 3-D cell, such as a cube, and store it in a library for future use is an obvious advantage when using such symbols to represent large amounts of data. The user only need identify the cell name and the origin at which the cell is to be placed. Cells as used in the context of this research represent point symbols only.

This completes our discussion of the IGDS nucleus software within the Intergraph computer graphics system. It is important to note at this time that other specific mapping application software is available within the Intergraph domain. Specialty software packages that pertain to the mapping field include World Mapping System (WMS), Digital Terrain Modeling (DTM), Terrain Modeling System (TMS), Edge Matching (EDGE), Terrain View/TDM (3D MAP), Elastic Body / Small Angle / Least Squares (EBSALS), Grid Data Utilities (GDU), and Graphic Polygon Processing Utilities (GPPU).

Figure 4.8. Standard view setup for the 3-D design file.



The left screen has 4 views. These are :

Top view
Front view
Right side view
Isometric View

The right screen displays the top view.

Source : Adapted from IGDS Users Guide, Version 8.8, P. 1-23, Intergraph Corp., January 1985.

These software packages are oriented towards specific applications and were either, not available, or offered little in terms of the research objectives of this study.

4.2.3 Application Software Interfaces

The ability to design and implement application software is a flexibility required of any computer graphics system today. Most mapping applications require user-written software interfaces to perform many of the processing tasks involved in spatial data management. One of the strengths of the Intergraph [illegible] system is it's direct interface with the standard VAX/VMS operating system. This affords users the flexibility of using software tools outside of the specific Intergraph routines. Accordingly, the application software interfaces utilized in this research can be discussed in the context of VAX/VMS and Intergraph. Since the VAX/VMS interfaces provide the majority of the utility and pre-processing functions it is proper to review these first.

User access to VAX/VMS services is provided by means of a command language. *Digital Command Language*, hereafter DCL, is the standard command language for VAX/VMS. DCL is a command driven interactive language that provides basic system services, initiates system utility programs, and initiates user programs. The majority of these capabilities involve the manipulation of data stored in user defined files. Intergraph format graphic files are compatible with the majority of DCL commands.

The VAX/VMS service used most in this research is *command level programming*. Special files called *command procedures* are created containing a series of DCL commands. When a command procedure is invoked the system will process the commands one at a time. Command procedures allow the user to catalog and automate a series of commonly entered commands. Commonly performed processes that may take several commands can be formalized and executed in future by means of one command procedure. In addition, one can take advantage of special DCL commands (ie. *lexical functions*), to perform programming functions such as assigning symbolic names, evaluating numerical and logical expressions, accepting parameters, and communicating with the interactive user. In the application software developed under the scope of this research, command procedures play an integral part in the pre-processing of the data. Several command procedures have been developed to perform a variety of utility functions. These include base map creation, data file sorting, help file access, data file manipulations, and program access. Program access refers to the creation of an environment that allows users access to all data processing programs. The *access environment* uses several menus to allow the user the ability to perform a variety of functions. The access environment and the command procedures involved are discussed in more detail in Chapter V.

Beyond command level programming VAX/VMS provides a comprehensive set of tools for developing programs including an interactive full screen editor (EDT), a sort/merge utility, a librarian facility, a FORTRAN compiler, a linker, and the VAX 11 Run Time Procedure Library. A brief description on the use of each is appropriate.

The full screen editor permits the quick insertion and editing of text within ASCII text files. This service was utilized for original data input and editing, as well as the writing of all application command procedures and FORTRAN source programs.

The sort/merge utility is invoked through one specific application procedure to allow the user the capability to easily re-sort data files as required. The sort utility was vitally important during the earlier stages of data cleaning, validation, and classification as discussed in Chapter III.

The librarian facility was used throughout the software development phase to help catalog and store the numerous routines. Three main libraries were maintained. These were for storing help files (help library), command procedures and source programs (text library), and compiled object modules (object library).

The VAX 11 Run Time Procedure Library provides a host of run time routines that allow for general variable manipulation, *I/O* functions, terminal independent screen handling, time/date functions, resource allocation, and condition handling. All Run Time Library routines are available through specific high level language (ie. FORTRAN) calls. In the application software developed, a small number of Run Time Library routines were used.

The VAX/VMS tool of most importance that was employed in the application software involved the use of the FORTRAN *compiler* and the *linker*. The FORTRAN compiler is a language dependent translator that converts programs written in FORTRAN source code to *object modules*. The linker searches appropriate object module libraries and links all modules referenced into an *executable image*. The executable image may be thought of as a complete machine code translation of the original source program. This executable image can be run on the operating system to perform the desired task. The simple conceptual steps involved in this process are illustrated in Figure 4.2.

The VAX/VMS operating system supports several high level computing languages. The language applied in this research is FORTRAN 77. This language was chosen for two main reasons. These are it's acceptance within the digital mapping field and more specifically, it's compatibility with IGDS software.

FORTRAN is somewhat of an industry standard within the digital mapping field. [43] It was developed for use with mathematical applications. [44] The field of digital mapping, or more generally geographic data management, is one that intrinsically involves the manipulation of coordinate systems and numerical values (representing data themes). Accordingly, the use of FORTRAN is quite appropriate. Another consideration that is directly related to FORTRAN's acceptance is its tranferrability. The FORTRAN language is widely used amongst the computer mapping community and correspondingly is supported in almost all computer processing systems. Therefore, programs written in FORTRAN are easily distributed and utilized by a wide variety of users. As well, programs coded in FORTRAN can be easily converted to other site specific languages (ie. *C*).

The primary reason behind using FORTRAN is it's compatibility with the IGDS interface software. Intergraph's IGDS interface subroutines are only compatibile with a small number of high level languages. FORTRAN exists as the fundamental interface language. Considering the reliance of this research on the Intergraph system the choice of FORTRAN was inevitable.

As previously mentioned the development of an application program on VAX/VMS requires a number of steps. These include compiling and linking. The complete program development process as applied in this research is presented in Figure 4.9.

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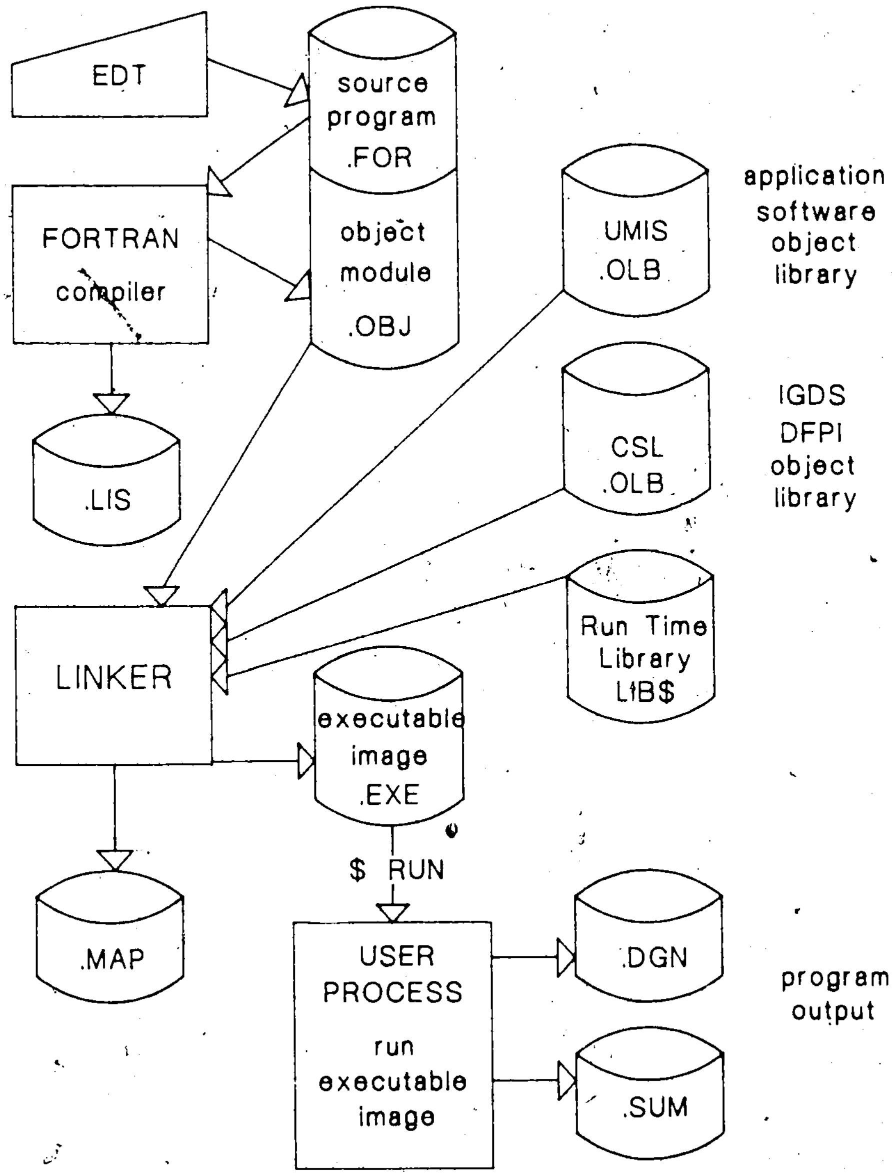
[43] It is understood that several mathematically inclined languages are being used for digital mapping applications in the field. However, the most common and accepted by far is FORTRAN.

[44] FORTRAN refers to FORmula TRANslation.

Figure 4.9. The program development process.



Source : Adapted from VAX/VMS Manual Set, Volume 6A, P. 1-4. Digital Equipment Corp. April 1982

Once the VAX/VMS software interfaces have been reviewed it is appropriate to discuss the Intergraph application interfaces that were employed. These consist of the use of the Design File Processor Interface Task, hereafter DFPI, and *user commands*, hereafter UCM.

On the VAX system, DFPI provides a number of interface subroutines to manipulate graphic design files. These are commonly referred to as DFPI FORTRAN interface subroutines, hereafter DFPIIS. These subroutines allow the user to place graphic elements in an IGDS design file using the DFPI task. "The subroutines simplify the user's interface to DFPI and provide maximum capabilities with a minimum knowledge of DFPI operations." [45] The transfer of data from the FORTRAN application program into the IGDS design file format is performed automatically by the DFPI task.

Any discussion on the use of DFPI would not be complete without a brief review of it's operating considerations. Several of these considerations are addressed as potential problems in the application software package as discussed in Chapters VI and VII.

The use of DFPI interface subroutines require an IGDS design file and cell file. "All files used by DFPI must be preallocated, *contiguous* files of sufficient size to contain all elements to be placed." [46] Only design files that consist of contiguous storage blocks can be viewed graphically and manipulated by DFPIIS. Any program using DFPIIS must call the INDFPI subroutine to initialize the DFPI task, and call the DEDFPI subroutine to detach the DFPI task when processing is finished. If DFPI is not detached properly the user will not be able to execute the application program again. This is due to DFPI employing the File Builder (FB) subprocess as its work horse. The use of the File Builder is consistent with the IGDS nucleus software. In an error situation as such, the FB subprocess must be stopped before execution of the application program can continue. DFPIIS support the placement of a wide range of graphic elements. In the application software developed only a small number of element types were required. These were cells, lines, and text. The appropriate subroutines used were CLDFPI, LNDFPI, and TXMTRX. A complete list of all DFPI subroutines used is presented in Table 4.1.

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[45] *IGDS Application Software Interface Document, Version 8.8,* Intergraph Corporation, Huntsville, Alabama. P. 6-1.
[46] *IGDS Application Software Interface Document,* P. 6-1.

Table 4.1. DFPI subroutines used.

Subroutine Name	Description
LKTCSI	A utility subroutine to convert file name to format required by DFPI.
INDFPI	Initializes DFPI and opens the design file and cell file for use.
RDTCBA	Reads Terminal Control Block (TCB) data using 6 character RAD50 name.
CLDFPI	Places user defined cell using angle and scale factor..
LNDFPI	Places a line as defined by two end points.
TXMTRX	Places text characters by a rotation matrix.
DEDFPI	Detaches DFPI and closes files.

Source : Subroutine information was obtained from IGDS Application Software Interface Document, Version 8.8, Intergraph Corp., January 1985.

A major consideration involved in using the DFPI subroutines is the continual support provided by Intergraph. The DFPI routines appear significantly important in Intergraph's interface approach. Obviously much work has gone into their development. This is not to say that they are without limitations however. These limitations are addressed in Chapter VI and VII. Recent upgrades to the IGDS nucleus software indicate a continued effort to enhance and support the DFPI subroutines. Consequently, the appropriateness of using DFPI may well outlive the theoretical considerations of the application software.

It is important at this time to put the use of DFPI in perspective considering the entire context of the application software. As previously mentioned, the VAX/VMS application tools are used primarily as pre-processing functions. File management utilities are most common. DFPI conceptually goes one step further and provides the fundamental processing tasks for the application software. All graphic production is accomplished using DFPI subroutines. The last step in the application process is post processing. These functions include graphic editing, element manipulation, and visual analysis. User commands provide some of the mechanism for this step. An understanding of the user command interface is required.

A user command can be defined as a customized sequence of graphic commands that are inserted into an ASCII file for use at a later time. The concept of user commands parallels that of the command procedure discussed earlier. The distinguishing factors being that user commands operate only in the IGDS GRAPHICS mode of operation, and they must be composed of specific *user command language* commands. Each user command exists as a series of ASCII text strings in a file on disk. "When a UCM is invoked, the *Command Interpreter* (CI) retrieves the file from disk, decodes each text string in the file, and performs the specified operation." [47] The purpose of specific UCM's can range from the simple definition of design file parameters to the more complex creation and manipulation of graphic elements. In the application software developed for this study UCM's primarily perform the functions of setting up design file parameters and activating specific application menus. A small number of UCM's have been developed to aid the user in the manipulation of graphic elements during the

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[47] *IGDS Application Software Interface Document, P.2-1.*

interactive editing stage. The ability to develop and invoke UCM's is a distinct advantage when one considers the interactive mapping concept. This UCM interface allows the user an open ended flexibility in defining and performing the editing and analysis functions that are required in the use of the 3-D cartographic image. Obviously, this interface affords many possibilities for future research into the definition and evaluation of the interactive editing process.

In summary several important points should be noted. The review of computer graphic processing concepts and the technology involved is complex in it's nature. Depending on the field of application not all conceptual or technological considerations are relevant. Consequently, the discussion of VAX / VMS and Intergraph is not complete. It is not intended to be. A review as such goes far beyond the bounds of this research. The brief overview of both systems and their interrelationships is only intended to establish a technological framework in which to place the context of this application study. Given that a general understanding of the technological tools has been established, it is now appropriate to examine the specific application software package developed for this research. This will be undertaken in Chapter V.

5. SOFTWARE DEVELOPMENT AND IMPLEMENTATION

The application software package that was designed, implemented, and tested in this thesis research has been entitled the Urban Mapping Information System, hereafter UMIS. UMIS was developed with respect to the four primary aims of this study as identified in Chapter I. These were to :

1. Integrate cartographic, geographic, and computer graphics approaches for the analysis of spatial data.
2. Provide a three-dimensional (hereafter 3-D) mapping method as an alternative technique for the effective display of temporal urban spatial data.
3. Provide a process that would allow for the analysis of urban change over time.
4. Implement a practical application that would make use of Intergraph's Interactive Graphics Design Software (IGDS) computer graphics system.

UMIS currently exists as a set of interrelated programs and procedures that are based on the technological tools as presented in Chapter IV. UMIS was designed and implemented within the conceptual framework of software development that is presented in Figure 3.4. Several important ideas permeate this development methodology. These are discussed in terms of practical system design considerations and development objectives.

5.1 System Design Considerations

The most important consideration was an attempt to incorporate current spatial data processing methodologies into the system design. A review of the abundant literature on system design concepts provided several pertinent ideas. These are presented below.

The notion emphasized most often in the literature involved extracting subsets of data from a master data base and processing these subsets individually. Accordingly, data subsets are of a temporary nature and are often expendable after graphics analysis and processing. Of course, this idea requires that several programs must be available

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The notion emphasized most often in the literature involved extracting subsets of data from a master data base and processing these subsets individually. Accordingly, data subsets are of a temporary nature and are often expendable after graphics analysis and processing. Of course, this idea requires that several programs must be available idea of independent data sets for both attribute and positional data is directly applicable to the concept of using data subsets. Data subsets, without the storage overhead of coordinate data, are more optimally suited for manipulative and analyical processing. This applies for most of the analytical functions required for point data. However, for more complex GIS analytical functions, such as those that are required by linear or polygonal data, coordinate information may be required.

A brief description of the attribute and positional data files used in this research is appropriate. The Bond Street case study employed for this research has four attribute files. As outlined in Chapter III, two data sets were used. One data set ranges from 1950 to 1980 in one year intervals, and the second data set ranges from 1840 to 1980 in five year intervals. Each data set is available in a file sorted by year first and address second, and address first and year second. These are referred to as the **yearly** sorted file and the **address** sorted file. Two cross sorted data files were required for each data set due to the practical processing considerations involved in fulfilling the three initial analysis concerns identified in Chapter III. The two cross sorted data files were also used heavily in the data cleaning, validating, and classification steps identified in Chapter III. Each file is approximately 0.38 megabytes in disk size.

The positional data for the Bond Street case study is located in one data file. This file is named BOND.XYZ and is referred to as the master coordinate file. The positional file was created by extracting X,Y,Z coordinates for selected point locations, ie. centroids representing street addresses, from a British Ordnance Survey map digitized into Intergraph IGDS design file format. The original base map was digitized into a 3-D graphics design file using Intergraph's IGDS software. After determining the required addresses and referencing these against known address locations for the 1980 base map, point locations were extracted for all required addresses. [50] A location was determined for all possible data set addresses. It should be understood that through time several addresses disappeared, reappeared, and amalgamated with other addresses. Often determining *mobile* addresses is a difficult problem. Accordingly, it was decided upon after consultation with the urban specialists, to provide coordinate locations for all possible addresses. It was hoped that with graphic analysis of the data set the process

[50] All addresses were determined during the data checking and validation procedures described in Chapter III.

of address *migration* would be more clearly identified. At that time modifications to the data files, positional and attribute, could easily be undertaken.

Coordinate extraction (X,Y,Z) for all possible addresses was achieved through a UMIS routine, written by the author, called GETCORDS.UCM. This user command is made available within UMIS to allow the user the flexibility of adding new address locations, or creating new master coordinate data files. In fact the Bond Street case study required a modified master coordinate file several times after some initial processing indicated errors in the location of some addresses. The positional file is utilized with readonly access by the UMIS software and is matched with the attribute data subset files as the last step before graphics processing. The address attribute item is the primary key for all coordinate matching.

The last practical system design consideration is more concerned with the technological tools to be utilized. Since part of the overall aim of this research is in fact a practical application of the Intergraph IGDS system, it is appropriate that software development make use of the Design File Processor Input (DFPI) graphic primitive subroutines. DFPIIS exist as the fundamental processing tasks for the application software. Chapter VII will offer an evaluative review of the applicability of these subroutines.

5.2 Development Objectives

While the system design considerations tend to be concerned more with conceptual questions of data storage and design strategies the development objectives for UMIS stress practical functionality. These are discussed below.

Perhaps the overriding theme evident in all of the UMIS procedures is their ease of use. [51] Prior to the development of the UMIS application software, this author was surprised at the difficulty and confusion inherent in operating other application software packages. Most of these *application* programs appear to be written by computer programmers for computer programmers. Consequently, the objective for all UMIS procedures was to be understandible to the application user, in this case the urban

[51] The term *procedures* is used in a generic sense to describe software programs, command procedures, text files, and user commands.

specialist, and easy to use. Complete documentation for all procedures was a priority. As well, an *on-line* help facility is available for interactive reference while operating the software.[52]

A notion that is directly related to the *user friendly* concept is an orientation towards the urban geographer. Wherever possible relevant terminology has been used for describing, prompting, and summarizing processing options available. The idea being that a researcher who is comfortable operating a software package will achieve more beneficial results than one who is not. Experience in the area of system design indicates that the user who is confused, frustrated, or intimidated by a software product will tend not to use it.[53]

Another major objective in the development of the UMIS software is flexibility. All the procedures within UMIS were designed and written around possible use with other data sets. This was a concern expressed early on in the stages of software development by the urban specialists. The modular approach to the development of the system provides an open ended product that allows for future modifications and the addition of specific application routines. The Bond Street case study and the three primary concerns expressed by the urban specialists form the fundamental base of the UMIS system. However, it was decided that flexibility with other data sets would ultimately determine the quality of the software.

Perhaps the most important development objective was to address the three primary concerns of initial inquiry by the urban specialists. These were :

i) The identification of spatial and temporal relationsips between functional activities at specific addressess.

ii) The identification of the average length of stay of all activities for specific addresses.

iii) The identification of activity persistence for specific addresses.

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[52] The term *on-line* refers to an interactive facility that is readily accessible via the computer operating system while the user is signed on to the system.

[53] This notion is well respected within the electronic data processing (EDP) profession. Studies into the ergonomic design of software stress the importance of making the user feel comfortable to obtain maximum productivity from that individual.

By fulfilling these needs the bounds of software development could be established. With this in mind it is important to note that UMIS is not intended as a comprehensive tool for the urban geographer. The current status of the application software only addresses the rudimentary pre-processing and post processing concerns, as well as the three primary graphics processing options.

The development objective of next importance was to fulfill the cartographic aims of the research. As identified in Chapter I two primary requirements define the cartographic aims of this study. These are to statisically measure and evaluate the data set, and to incorporate the inherent advantages of 3-D representations. A brief review of both goals is appropriate.

From a strict cartographic sense the process of statistically measuring and evaluating data subsets is required. The use of qualitative data, as in this case study a nominal data set, justifies the use of statistical analysis in order to obtain a descriptive measure of the data. This type of data analysis fulfills the data manipulation step of the data handling model presented by Robinson et al, 1978, P.129. As well, it conveniently fits into component three of the GIS model as proposed by Marble. This allows the user to measure and evaluate their extracted data subsets before graphics processing is undertaken. For the data sets that are utilized in this case study, the most appropriate measure of central tendency with which to summarize a nominally scaled distribution is the *mode*. The most commonly used associated index of variation is the *variation ratio* (Robinson et al, 1978).

In any nominal distribution the *mode* is the class that occurs most frequently. As in the Bond Street case study the *modal class* is the SIC code that occurs most frequently through time for a given data subset. As previously discussed, a primary design consideration was to extract data subsets for individual processing sessions. The measurement of the modal class would be very useful in evaluating the content of the data subset before graphics processing.

In an effort to indicate how representative a modal class is of a given distribution (data subset), a variation ratio can be calculated. The variation ratio (V) can range from 0 to 1. The nearer V is to 0 the better the quality of the mode as a summarizing statement.

The variation ratio is calculated by

$$V = 1 - (f\text{-modal} / n)$$ where

f-modal is the number of occurrences in the modal class

n is the total number of occurrences

A modal analysis of the data subset can be particularly informative when considering that data can be extracted for specific addresses through varying time periods. The content of a data subset is completely user defineable. The user may have no idea what the distribution (data subset) is composed of. This is especially true if the data subset was selected based on an address criteria.

The modal analysis step for processing qualitative cartographic data is incorporated in UMIS through a subroutine called MODAL-DAT. After a data subset is extracted the temporary attribute file is automatically processed with the MODAL-DAT subroutine. An added option of modal analysis by yearly intervals is also available but must be specifically requested by the user (MODAL-YEAR). Sample modal analysis statistics are presented with the UMIS examples in Chapter VI.

The second cartographic aim, and perhaps the one that is most relevant, is to incorporate the inherent advantages of using 3-D representations in the spatial display and analysis of the data subsets. In fact the three initial concerns expressed by the urban specialists were developed around the ability to utilize three axes for displaying data. In all three graphics processing options the third dimension (Z axis) is used to display different data variables. This variety in use, along with the intervention of other visual variables (ie. colour), allows the user to utilize the 3-D representation in three different ways.

5.3 UMIS Overview

The UMIS application software package was designed, implemented, and tested with respect of the four primary research aims. UMIS currently exists as a set of interrelated programs and procedures that are dependant on the following software:

1. VAX Virtual Memory System (VMS) Operating System Version 4.0
2. Intergraph Interactive Graphics Design Software (IGDS) Version 8.7 or higher.

All UMIS procedures were based on the technological limitations of the above software, and any changes in the structure, storage, and/or operation of said software may affect the operation of the UMIS package.

The framework of software development for UMIS was based on several pertinent system development concepts. These were discussed in the previous section of this chapter.

The UMIS software was designed around a research initiative involving the Bond Street data set. This data set includes urban retail data items for the Bond Street shopping street covering the periods 1840 to 1980. The data set is included with the UMIS software as a demonstration data set. Three initial research aims that were identified for urban retail infrastructure study became the focus for UMIS development. These were reviewed earlier in this chapter.

In considering the basis of the UMIS system several data set design considerations require identification. These are :

1. UMIS is only valid for use with *point* data. Point data is representative of discrete X,Y locations on the earth's surface and infers no interrelationships with *linear* or *polygonal (areal)* geographic features.
2. The primary attribute items are **year**, **street address**, and a classification **code**. For the case study, a six digit hierarchial classification code was used to represent Standard Industrial Classification (SIC) activities. Each record in the attribute data file contains a year delimiter, a street address, and a functional classification code (SIC).

Within UMIS the term *access environment* is used to describe a command procedure that allows users access to program selection menus. The access environment supplies a variety of menus to allow the user to perform selective tasks. This concept is the basis for interaction with the UMIS software. The three graphics processing options identified earlier are all accessible via the UMIS access environment.

5.3.1 Graphics Processing

The graphics processing options are the most important aspect of the UMIS software. Three basic programs are available to create 3-D graphics design files. Each is based on a fundamental geographic aim as identified in Chapter III. The goal of each program is reviewed below.

1. **Yearly Establishment Analysis * YEARLY-ESTAB**

   The identification and display of spatial and temporal relationships between activities at specific street addresses.

2. **Average Length of Stay Analysis * AVG-LENGTH**

   The identification of the average length of stay of all activities for specific addresses.

3. **Duration of Function Analysis * DUR-FUNCTION**

   The identification of activity persistence at specific addresses throughout the entire time period.

The term *activity* refers to the classification code assigned to a specific street address at a particular time. In the Bond Street case study activity refers to the urban retail function expressed as a six digit modified Standard Industrial Classification (SIC) code. It is important that the user has a good understanding of the content of the data set, as well as complete knowledge of the classification scheme that is being utilized. Use of the UMIS graphics programs necessitates that the user understand what subsets are being extracted and the geographic implications of their use. A brief overview of each graphics program is required.

Yearly Establishment Analysis * YEARLY-ESTAB

The YEARLY-ESTAB procedure is the main graphics processing program within UMIS. This program was developed to fulfill the primary geographic aim of identifying the spatial relationships between activities at specific addresses for specific time periods. YEARLY-ESTAB will create a map that displays point symbols as 3-D building like pillars. The YEARLY-ESTAB procedure makes use of the three main attribute items. These are the data item year, the street address, and the classification code.

The classification code represents the qualitative attribute. In the Bond Street case study this refers to the urban retail activity described by the modified Standard Industrial Classification six digit code.

Within YEARLY-ESTAB three graphic axes are utilized. The X and Y axes are used to define the positional location of an address, while the Z location is used to define the exact year of the data item. The visual variable *colour* is used to define the code activity. The colour coded cell selected for placement can be chosen to represent one specific activity or a range of activities. [54] The term *activity* is analgous to classification code. One cell is be placed for every address for a specific time period. For example, consider the street address "N001" from the Bond Street data set. The user could extract data only for this address. In the conversion of the data file to graphics the user would place colour coded cells based on a specific code or range of codes. A complete understanding of the classification scheme is a necessity. This would result in a 3-D map where cells were only placed for the street address "N001". Given the code distinctions defined by the user different colour cells would be placed for each criteria. Cells would be stacked on top of each other for the time periods. The bottom cell on the pillar would represent the earliest time period. Accordingly, the top cell of the pillar would represent the latest time period. The colour of the cell would represent the user defined code distinction.

With the Bond Street case study as an example the colour of the cell would represent the type of retail activity. A comprehensive knowledge of the classification scheme is required by the user to define the code distinctions. The user can choose to distinguish at a very fine level of classification (ie. shoe/boot manufacturer (618211) versus shoe/boot maker (618212), or at a very coarse level of classification (ie. primary industry (1xxxxx) versus retailing/tertiary activity (6xxxxx).

[54] It should be noted that with the Intergraph IGDS software colour is static for 3-D normal cells. Colour is defined at the time of cell creation and consequently different cells must be used if different colours are required. Accordingly, the YEARLY-ESTAB module provides the user with the flexibility of multiple processing passes using different cells to create a 3-D map.

Average Length of Stay Analysis * AVG-LENGTH

The AVG-LENGTH procedure calculates the average length of stay of all classification codes for selected addresses, and displays the average value as a cell pillar. The height of the cell pillar corresponds to the average length of time in years that all classification codes were present at a specific address. The AVG-LENGTH procedure makes use of the three main attribute items. These are the data item year, the street address, and the classification code.

Within AVG-LENGTH three graphic axes are utilized. The X and Y axes are used to define the positional location of an address while the Z location is used to define the average number of years any classification code was located at a specific address. Hence the Z axis increments sequentially in years from the base map location. The base Z value would be 0. The Z value can be thought of as the elevation. However, with AVG-LENGTH the elevation is represented by the number of years. The height of one cell would equal one time period in years (ie. 2.5 metres = five years). The user should be aware that due to the nature of the statistical analysis yearly intervals that exceed two years are not valid. An averaging technique as such would incorporate too large a margin of error if the yearly interval used was greater than two years. Accordingly, this procedure is best suited for data sets with a one year data interval. The program will validate and warn any user who attempts to use data with yearly intervals greater than two years.

The visual variable colour is used to distinguish a user defined selection criteria. The selection criteria may be defined as a range of values or as a range of addresses. Colour coded cells are placed based on the selection criteria. The term *value* refers to the average length of stay in years for a specific address. Current average values can range from 0.0, where no classification codes at all existed for the entire time period at a specific address; to 100.0, where only one classification code existed for the entire time period (100 time periods maximum). A value of 1.0 would indicate that the average length of stay for a classification code at a specific address is one year. In the case of a 100 time period data set (the maximum), a different classification code must have been present for every time period. One cell would be placed for every address for a specific time period if the value for that address was within the user's value selection criteria, or if the address was within the user's address selection criteria. Users can only select items for placement by defining either a range of average values or a range of addresses. For example, consider the Bond Street case study. In the conversion of the data file to graphics the user would plac ' ur coded cells based on a specific range of values or addresses. This would result in a 3-D map where cells were only placed for addresses that fall into the defined selection criteria. Given the selection distinctions made by the user different colour cells could be placed. Cells would be stacked on top of each other. The height of the pillar would represent the average value in years. Depending on the monthly accuracy selected, the average value would be rounded off accordingly. The level of vertical exaggeration for the cell pillar is determined by the monthly accuracy. The colour of the cell would represent the user defined selection criteria ie. a range of values or a range of addresses.

Duration of Function Analysis * DUR-FUNCTION

The DUR-FUNCTION procedure calculates the duration in years that a classification code has been at a selected address for the current time period. The height of the cell pillar corresponds to the accumulative number of years, or duration, that a classification code has been present at a specific address. The DUR-FUNCTION procedure makes use of the three main attribute items. These are the data item year, the street address, and the classification code.

Within DUR-FUNCTION three graphic axes are utilized. The X axis is used to define the positional location of an address, the Y axis is used to represent time periods, in even increments away from the address X,Y origin, and the Z location represents the cumulative number of years (duration) a current classification code has been located at a specific address. Hence, the Z axis increments sequentially in years from the base map location. The base Z value would be 0. Each cell height would be equal to one time period in years. The Y location for an X address on the street would represent the earliest time period for the data set. Yearly time periods would increment sequentially away from the street dependant on the cell width. The width of the cell represents one time period in the Y direction.

The visual variable colour is used to distinguish any data subset the user desires by utilizing a yearly selection, an address selection, and a duration value selection criteria. The cell selected for placement can be chosen to represent any combination of the above attribute criteria. The *duration* value refers to the accumulative number of years, not yearly intervals, that the current classification code has been present at the specific address. Duration values can range from the number of years representing the yearly interval (ie. one or five years for the Bond Street case study), to the maximum number of years for the entire data set (ie. 30 or 140 years for the Bond Street case study). Every time a new classification code is present at an address the accumulative duration would start with the lowest possible value (the yearly interval). If no classification code was present at a specific address for a specific time period no cell would be placed.

The pillar map that results from DUR-FUNCTION processing has a cell placed for every time period of every address. The height of the cell corresponds to the duration value. Time (Y axis) increments with the most recent time period, (ie. 1980 for the Bond Street case study), at the address X,Y origin. Earlier time period cells are placed incrementally in a direction away from the street frontage.

All three graphics processing programs make use of a summary file for logging the statistics and options of data extraction and map creation. A single summary file is created for daily processing with the following naming convention : DEVICE:[GGG,NNN]-STATS-'date'.SUM. An example summary file would be QSA1:[267,10]-STATS-MAR1.SUM. After being created in the first processing session for a given day, the summary file is appended to for all successive processing sessions. The file is saved on disk as an audit trail for the user and must be deleted by the user if desired.

Sample graphic products are presented in Chapter VI. Data flowcharts for each graphics program are presented in Figures 5.1 to 5.3. Note that the data flowcharts depict the normal flow of information from start to finish utilizing a specific program.

Figure 5.1. YEARLY ESTAB Data Flowchart

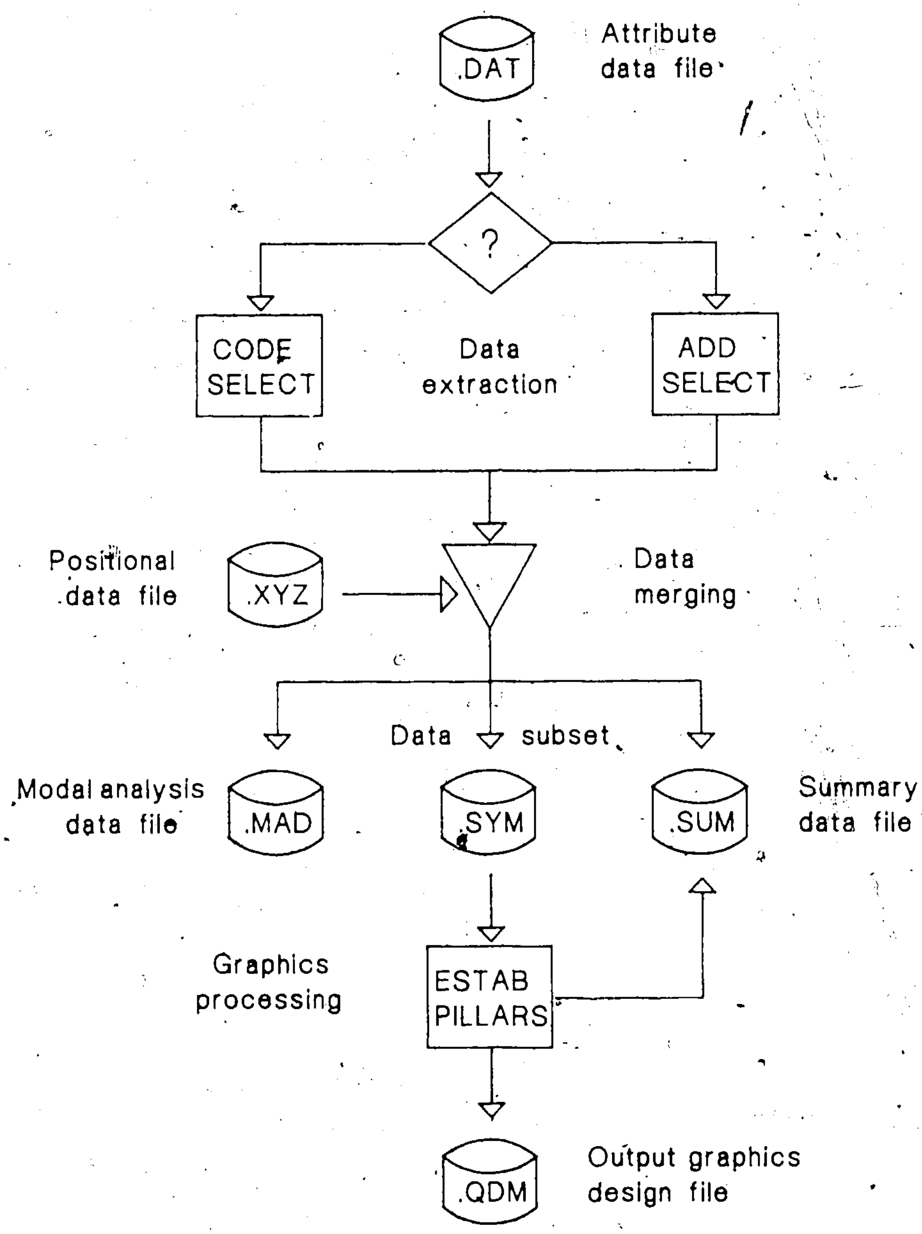
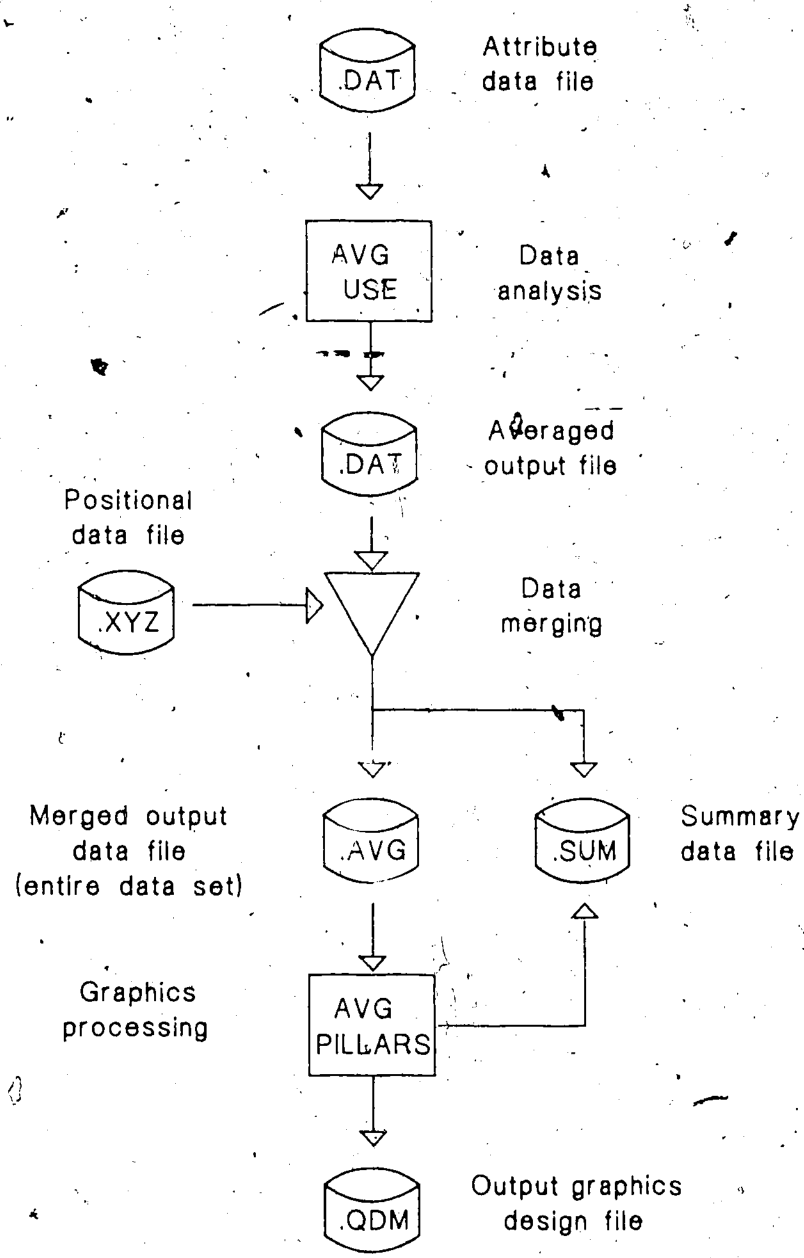
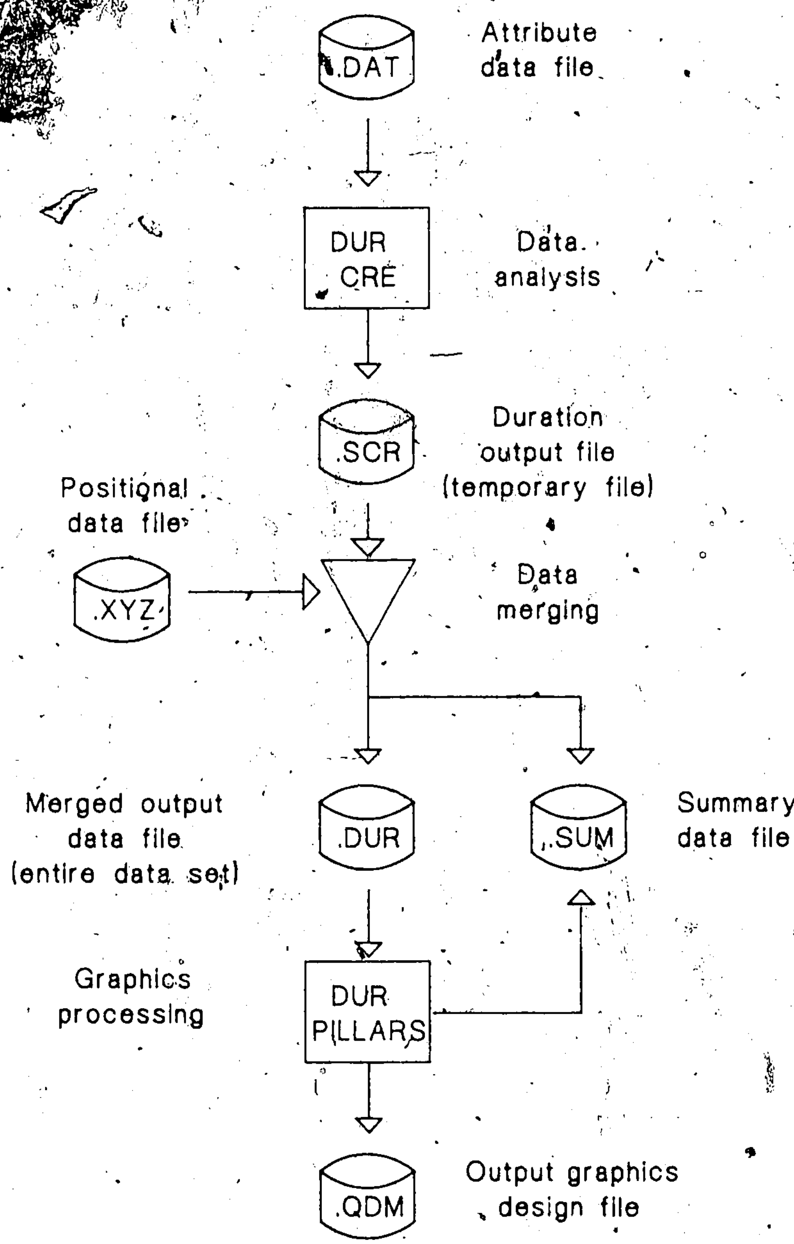


Figure 5.2. AVG LENGTH Data Flowchart



5.3. DUR FUNCTION Data Flowchart



6. APPLICATION AND RESULTS

This chapter presents one example for each of the three graphics processing programs. Each example is intended to address a pertinent geographic research problem as identified by the urban specialist. As well, the examples provide criteria with which the goals of the research, as identified in Chapter I, can be tested and evaluated. A brief discussion of each hypothetical problem is provided prior to the presentation of the graphic results. The discussion of the map products includes both a cartographic and geographic evaluation. The cartographic evaluation is concerned with the quality and clarity of the graphic results as well as the process of data handling. A discussion of the data processing statistics is included. The geographic evaluation is more concerned with the interpretive results of the processing. Salient characteristics of urban change are highlighted. The process of visual analysis is especially important.

The reader should be aware that the visual analysis process is based on the three dimensional dynamic viewing of the map product. Accordingly, exact reproduction of the graphic representations is not possible in printed form. The two dimensionality of the hardcopy paper medium does not allow viewing in a dynamic mode. The map products that are included in this chapter have been selected to present views that best represent the discussion that follows for each program example. Also, each perspective map makes use of different viewing azimuths and elevation angles. The vertical exaggeration is consistent for all map products and is independent of the perspective view. All three dimensional views were created using isometric perspective. Isometric perspective has the advantage of commensurability in all directions. This is the default for the Intergraph IGDS software. Due to the dynamic nature of the map viewing process, and the static nature of the focused perspective alternative, isometric perspective was used for all views. [55]

The second section of the chapter discusses practical considerations. This includes a review of the cartographic components of the map products. Problems and limitations are noted. Technical observations from the three examples complete the chapter. These include a discussion of the practical considerations of elapsed and

[55] Focused perspective viewing is only available through using Intergraph's Hidden Line Removal (HLINE) Software. These views cannot be dynamically manipulated in any manner.

processing time (CPU), and output file sizes.

6.1 Example Map Products and Discussion

The discussion of each sample problem involves the visual analysis process as well as use of the attribute data files. The SEARCH routine available within UMIS allows the user to substantiate patterns by reviewing the attribute data files or the attribute classification scheme. Use of the SEARCH routine was a necessary step in the examination of each sample problem.

6.1.1 YEARLY-ESTAB : Identification of Stationers

As noted in previous chapters the primary graphics processing program within UMIS is the YEARLY-ESTAB program. YEARLY-ESTAB allows the user to identify spatial and temporal relationships between functional activities at selected addresses. An area of immediate interest for the urban specialist was the identification and investigation of a traditional commercial activity on Bond Street. Of particular concern was the process of functional evolution. Selected commercial activities often evolve over time into more modern contemporary functions. A classic example of such an evolutionary function is that of the *stationer*. Simply defined a stationer is one who sells writing materials such as paper, pens and ink. The stationer function on Bond Street is a high order traditional activity that has existed for well over ninety years. In particular, one proprieter, Frank Smythson of 54 New Bond Street, has remained since the late 1800's. The use of a stationer data subset allows for the testing and evaluation of the YEARLY-ESTAB program, as well as provides a well defined case study for analysis. Smythson serves as a focal point for the investigation.

The first step in using YEARLY-ESTAB is to clearly define the data subset limits. In reviewing the classification scheme a range of stationer related functions were quickly identified. An attempt was made to incorporate the activities that the urban specialist believed may be serving the stationer function presently. It should be noted that the stationer function is a traditional type of commercial activity that is only commonly found in higher order retail areas today. A list of thirteen different Standard Industrial Classification codes were selected. Using the CODE-SELECT option of the

YEARLY-ESTAB program a data subset was created. The thirteen different classification codes were grouped into six distinct categories. Graphic symbol placement was based on these six groupings. The six categories of stationer activity are presented in Table 6.1.

The data extraction programs within YEARLY-ESTAB provide a variety of statistical measuring options with which the user can obtain a descriptive measure of the data subset. The user should be aware of the data content before any meaningful graphics processing can be undertaken. Modal analysis provides the primary means of evaluating the content and distribution of the data subset. In an effort to indicate how representative the modal class is of a given distribution, a variation ratio was calculated. The variation ratio (V) can range from 0 to 1. The nearer V is to 0 the better the quality of the mode as a summarizing statement. It should be noted that the data subset was extracted by identifying thirteen distinct classification codes. All the codes are closely related in function. An index of variation was calculated for each level of the classification hierarchy. It is only at level five that the data subset become somewhat diverse. This was expected as all the codes represent similar functions. At the fifth level of the hierarchy 93 of the 187 total data records have the code *65111*. The *65111* classification is reserved for bookseller related functions. The variation ratio of 0.50 reflects that this modal class is not very representative of the entire data subset. The sixth level of the hierarchy reflects an even greater diversity in the data distribution. The variation ratio of 0.65 indicates that the modal class *651*[illegible] is not at all statistically typical of the data subset. The most frequently occurring class is *651131* where only 67 of 187 records are found. The *651131* code defines the stationer function. The modal analysis data is presented in Table 6.2.

To further measure the content of the data subset the ESTAB-HISTO program was used to create a histogram representing the temporal distribution of the data. This histogram identifies the frequency of data records for each year of the time period. The histogram for the stationer data set clearly reflects the traditional nature of the retail activity. Seventy-five percent of the data subset is found prior to 1905 and twenty-four percent of the data is dated between 1840 and 1850. From 1915 to 1980 an average of only three stationer related activities exists for each time period. The high for any

Table 6.1. Categories of Stationer Activity

Category 1

651131	Stationer

Category 2

651115	Bookseller Stationer
651116	Bookseller / Stationer / Library
651132	Stationer Bookseller

Category 3

651134	Stationer Dresscase Maker

Category 4

651135	Printer / Stationer / Newsagent

Category 5

579110	Office Furnishings

Category 6

651111	Bookseller
651112	Antique Books
651113	Bookseller Pupl.
651114	Bookseller and Library
651121	Library
651122	Library and Opera Agent

Table 6.2. YEARLY-ESTAB Modal Analysis Data

Modal Class Analysis Summary

1st Level of Code Hierarchy
MODAL CLASS Classification Code > "6"
MODAL CLASS Occurrences....> 184
Total Data Records.........> 187
INDEX OF VARIATION > 0.02

2nd Level of Code Hierarchy
MODAL CLASS Classification Code > "65"
MODAL CLASS Occurrences....> 184
Total Data Records.........> 187
INDEX OF VARIATION > 0.02

3rd Level of Code Hierarchy
MODAL CLASS Classification Code > "651"
MODAL CLASS Occurrences....> 184
Total Data Records.........> 187
INDEX OF VARIATION > 0.02

4th Level of Code Hierarchy
MODAL CLASS Classification Code > "6511"
MODAL CLASS Occurrences....> 184
Total Data Records.........> 187
INDEX OF VARIATION > 0.02

5th Level of Code Hierarchy
MODAL CLASS Classification Code > "65111"
MODAL CLASS Occurrences....> 93
Total Data Records.........> 187
INDEX OF VARIATION > 0.50

6th Level of Code Hierarchy
MODAL CLASS Classification Code > "651131"
MODAL CLASS Occurrences....> 67
Total Data Records.........> 187
INDEX OF VARIATION > 0.65
----

date is sixteen occurrences in 1850 and the low is two occurrences for 1980. Clearly the stationer activity was one which flourished in the retail environment of the 1800's but has become scarce during contemporary times. The temporal distribution histogram is presented in Figure 6.1.

Graphic representations were created using the ESTAB-PILLARS option of the YEARLY-ESTAB program. A stepped methodology was used which would allow the user the capability to evaluate data in the six distinct data groupings identified earlier. This process takes into account the dynamic display capabilities of the Intergraph technology as well as the visual analysis process discussed in Chapter I. The visual analysis concept proposes an iterative process that uses the map as a temporary product. The geographer interprets the map product and may choose to refine or alter the data selection criteria to create a new map product. The temporary nature of the map allows the viewer to modify the data selection criteria in an ad hoc manner or by some predefined methodology. The exact process is dependent on the content and prior knowledge of the data subset by the map user. The specific example presented here has utilized a methodology for the creation of the map products. The selection criteria used in this example is based on six distinct groupings of Standard Industrial Classification codes. No street address or year delimiters were identified.

The first map product was created by selecting only the stationer code (651131) from the data subset. Sixty-seven cells were placed representing thirteen addresses. The map showing the entire street is presented in Figure 6.2. Of the thirteen addresses with the stationer function ten are located on the north end of Bond Street. Only three are located on the south end of the ribbon, and only 1 (0001A) is located on Old Bond Street. As well as the spatial distribution pattern, the graphic representation indicates that the majority of the stationers were present between 1875 and 1905. This pattern is consistent with the entire data subset histogram where seventy-five percent of the activities were present before 1905. However, the stationer activity only accounts for thirty-six percent of the entire data subset.

A closer look at the north end of the street is presented with Figure 6.3. This view clearly shows the concentration of stationer activity prior to 1915. The two notable exceptions are Smythson at N054 and Mudie and Sons at N115. Smythson is

Figure 6.1. Temporal Histogram for YEARLY-ESTAB.

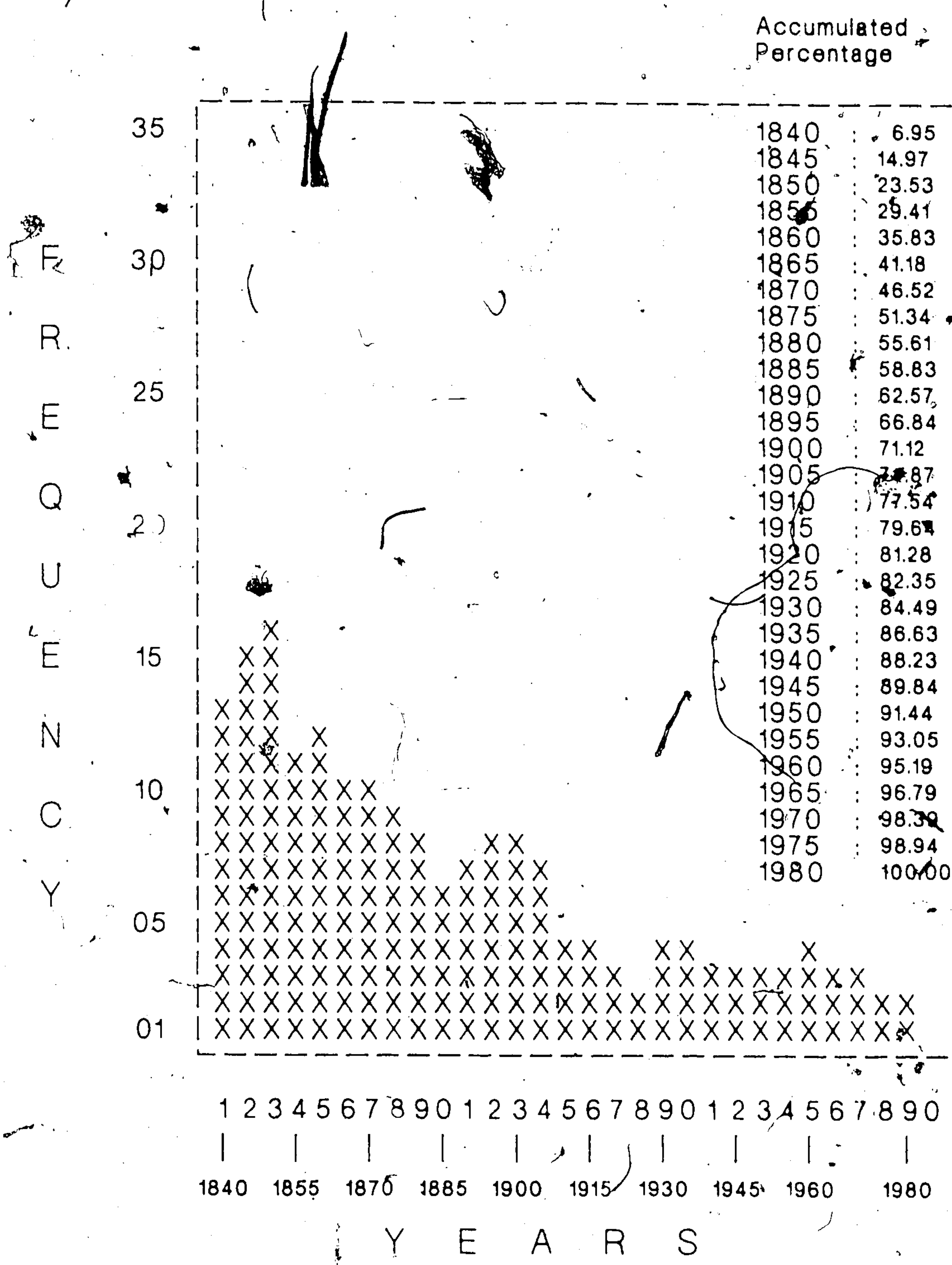


Figure 6.2. YEARLY ESTAB : Stationer Category I

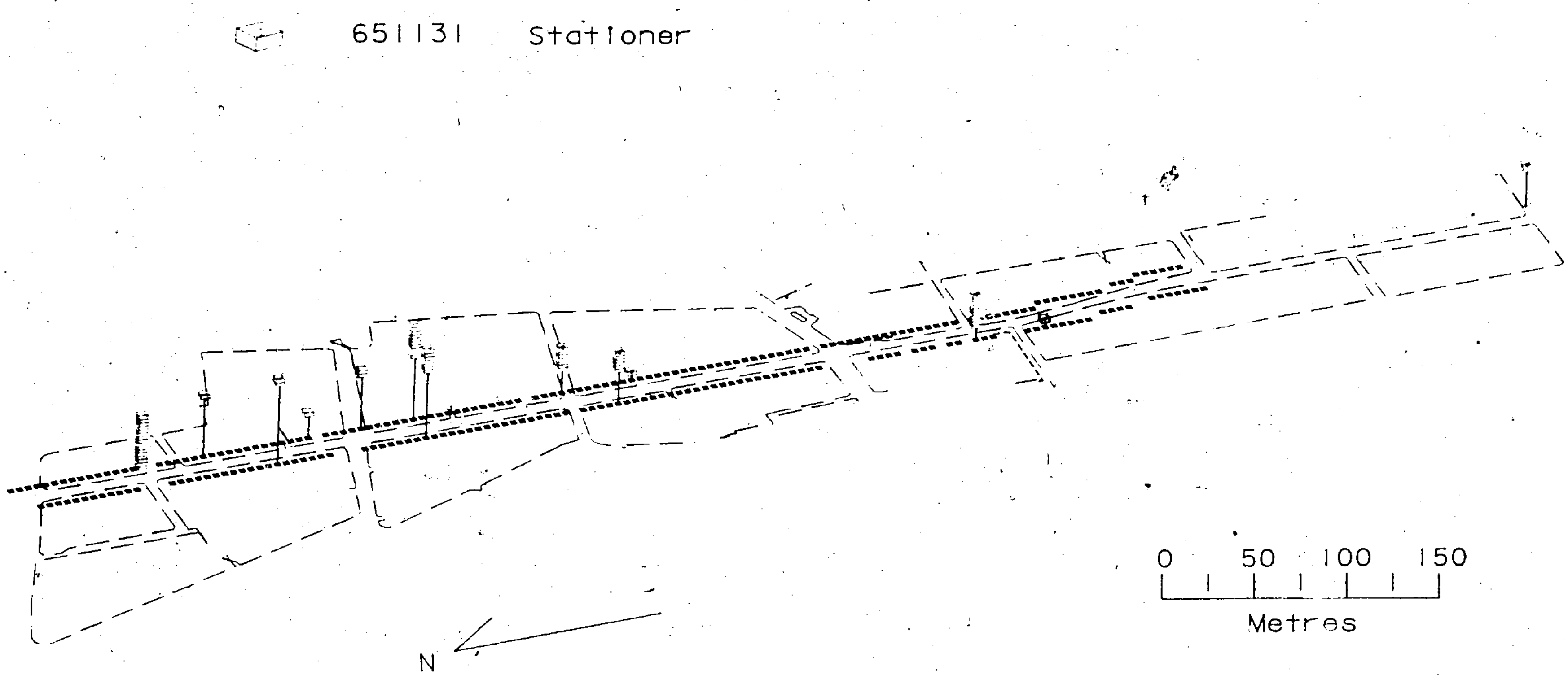
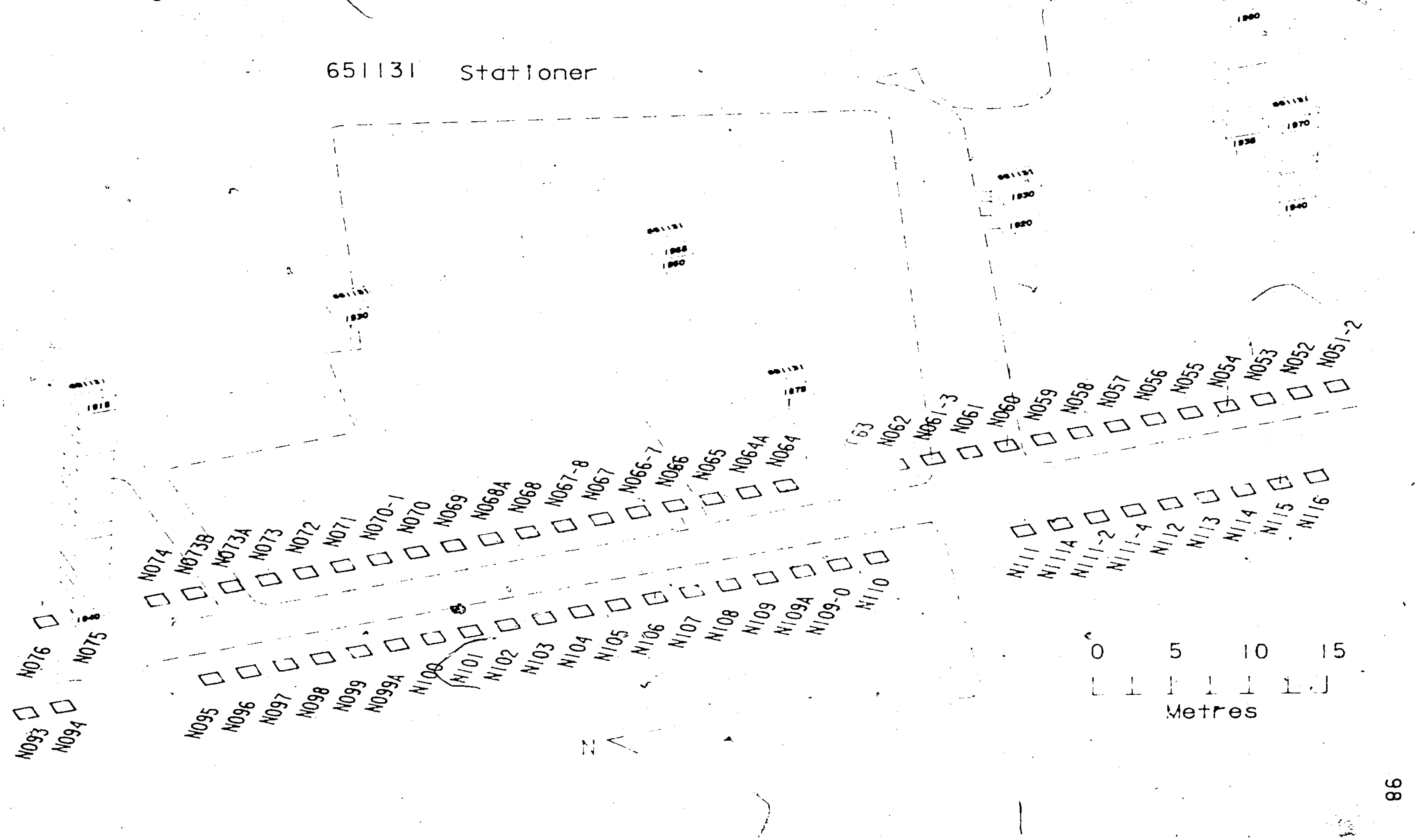


Figure 6.3. YEARLY ESTAB : Stationer Category I Zoom

651131 Stationer



present as a stationer on the street from 1890 to 1980 at N133 (1890-1915), N060 (1920-1930), and N054 (1935-1980). As well, note the presence of stationers at N075 for sixteen straight time periods beginning in 1840. Lockw [illegible] ain proprieter for fifteen of these periods.

The second map product was created by adding groups [illegible] rough four. These groups include the *bookseller stationer*, *stationer - dresscase maker*, and *printer stationer newsagent* classifications. This map constitutes the second step of our methodology. The map showing the entire street is presented in Figure 6.4. Eighteen cells were placed representing seven addresses. All seven addresses are located in the north end of the street. A definite clustering of activity is located here. As well, all eighteen occurrences of the new category exist between 1840 and 1870. The traditional nature of this category is evident. The addition of this grouping to the set of original stationers confirms our observation that the distribution is clustered in the north end of New Bond Street, and the temporal distribution is concentrated between 1840 and 1905.

Figure 6.5 shows the same windowed view as is presented in Figure 6.3. Little significant change has occurred. The only notable change is the addition of three occurrences for address N064. It appears that N064 was a *bookseller / stationer* for three time periods before changing into a strict stationer for one time period. A review of the master data file indicates that a change in proprieter occurred also. The reader should note that Figure 6.5 does not include codes *651134* and *651135* in the map legend because no occurrences exist in the particular window.

The final step in the visual analysis methodology involve [illegible] ding groups five and six. These categories include *office furnishings*, *booksellers*, *antique books*, and *library* activities. These functions can be defined as being on the fringe of the traditional stationer activity. One hundred and two cells were placed representing thirteen addresses. Three different perspective views are presented in an effort to properly represent the distribution of the entire street. These are Figures 6.6, 6.7, and 6.8.

The addition of the *fringe* stationer activities has distinctly changed the distribution on the street. These groups constitute fifty-five percent of the entire data

Figure 6.4, YEARLY ESTAB : Stationer Categories 1 - 4.

651131 Stationer

651115 651116 651132 Bookseller / Stationer

651134 Stationer / Dresscase Maker

651135 Printer / Stationer / News Agent

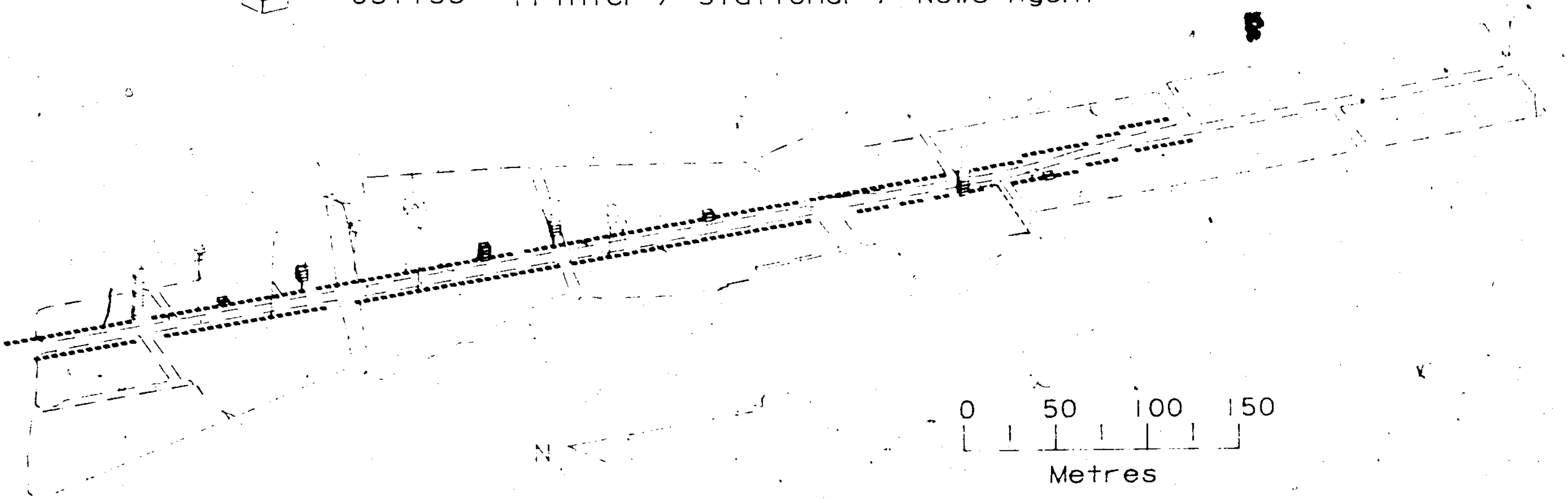


Figure 6.5. YEARLY ESTAB : Stationer Categories 1 - 4 Zoom

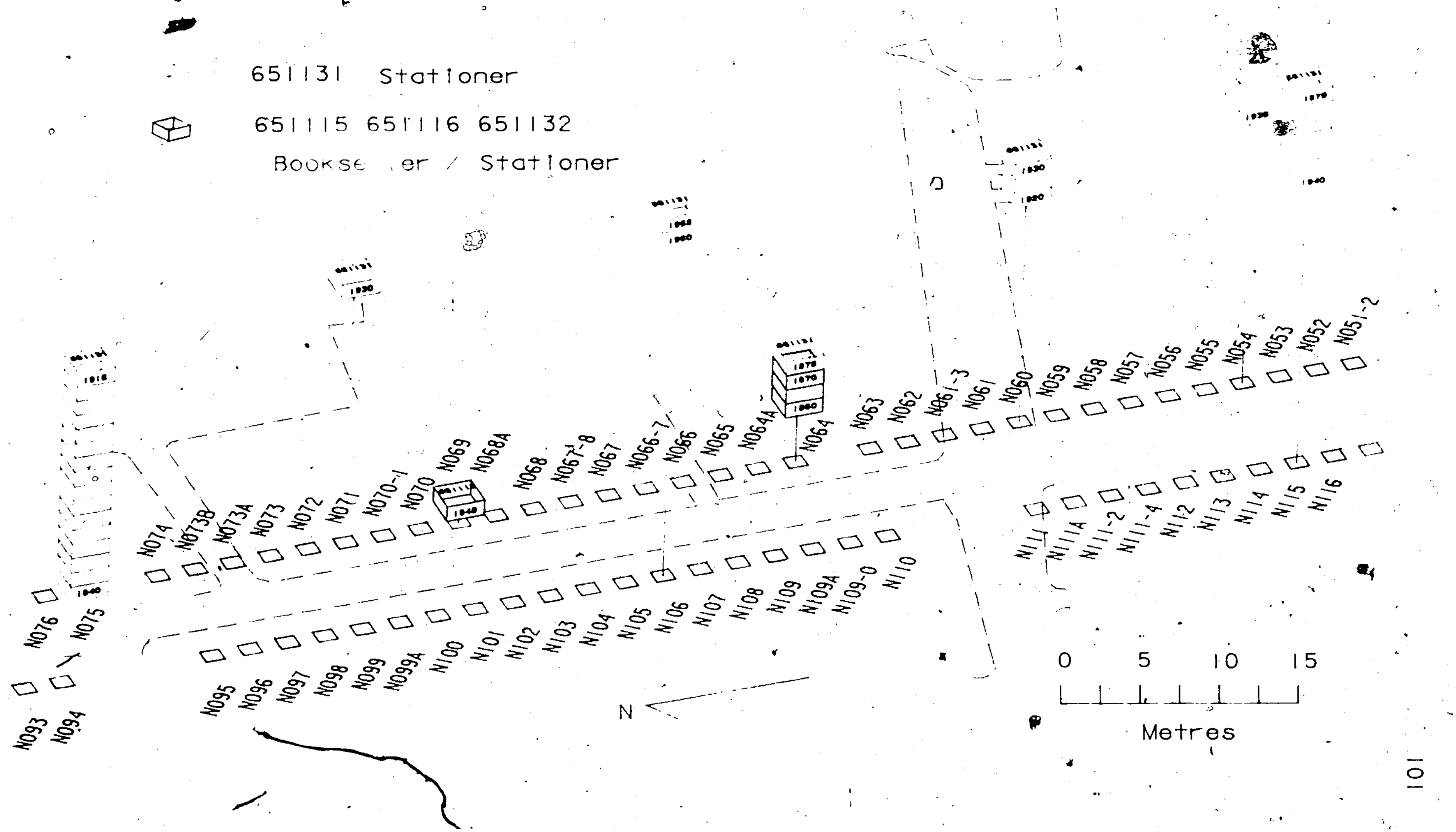


Figure 6.6. YEARLY ESTAB : Stationer Categories 1 - 6 View 1

651131 Stationer

651115 651116 651132 Bookseller / Stationer

651135 Printer / Stationer / News Agent

579110 Office Furnishings

651134 Stationer / Dresscase Maker

651111 - 651114 Bookseller / Library

651121 - 651122 Library

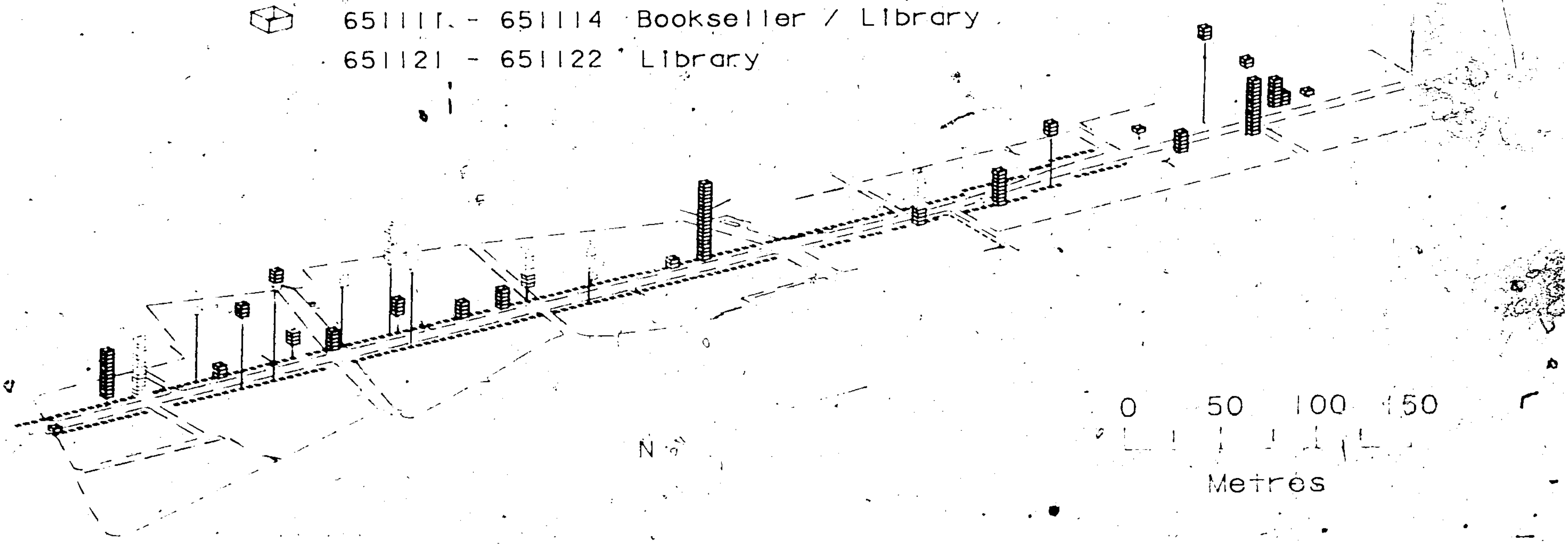


Figure 6.7. YEARLY ESTAB

Stationer Categories 1 - 6

View 2

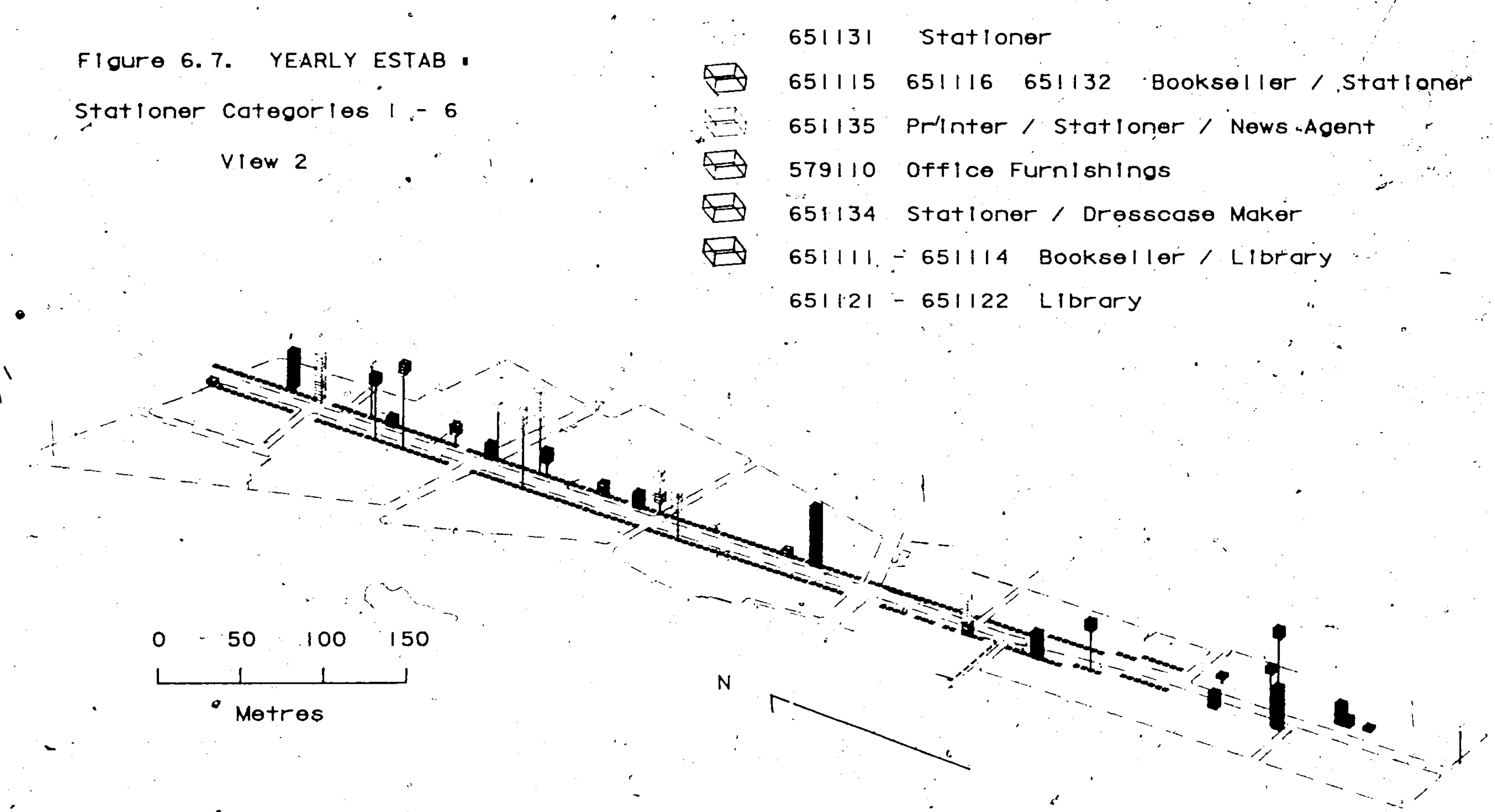
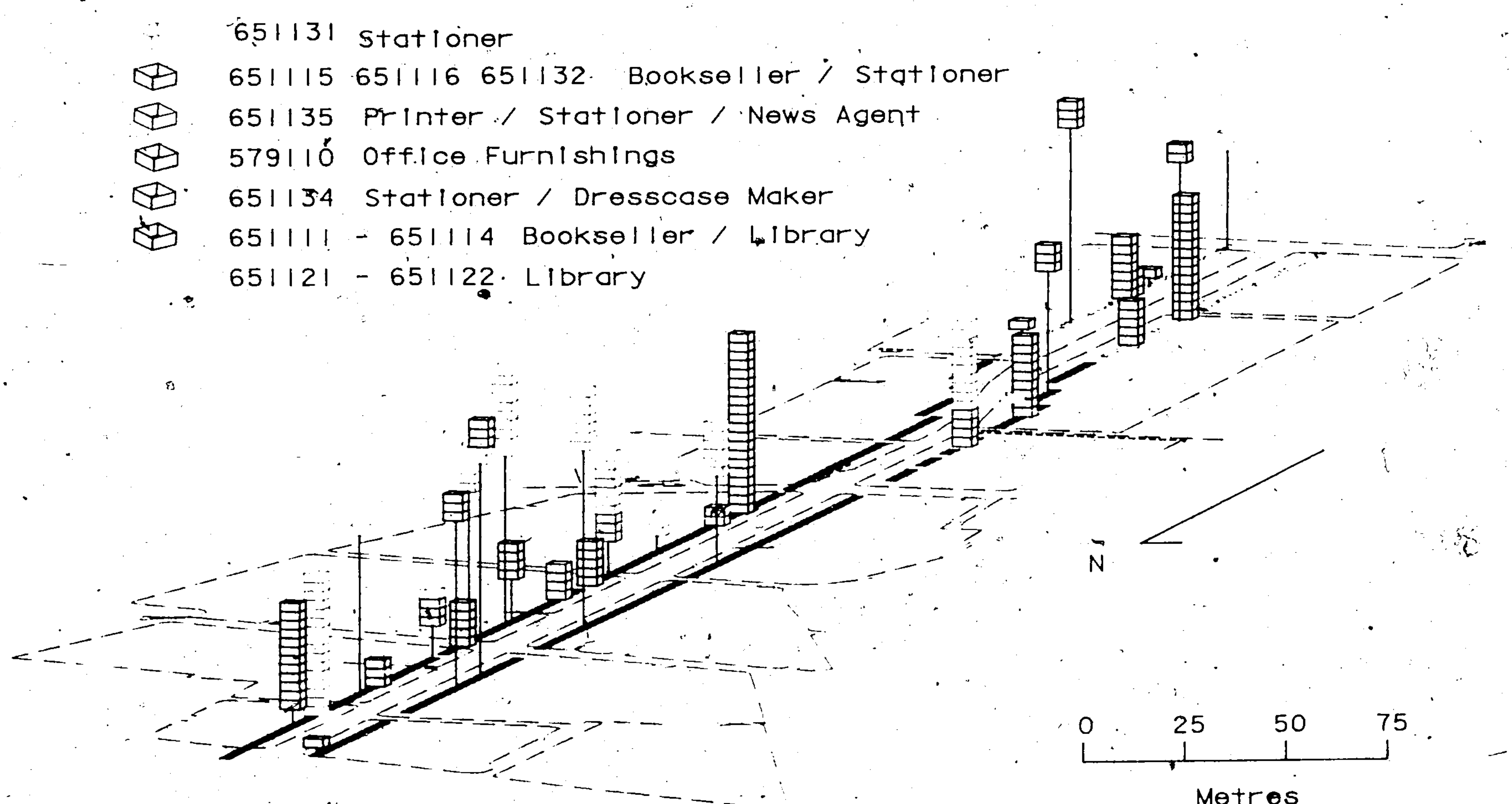


Figure 6.8. YEARLY ESTAB : Stationer Categories 1 - 6 View 3



subset. The occurrence of categories five and six are evenly distibuted spatially on the ribbon. In fact the view presented in Figure 6.8 shows a slight grouping of locations in the Old Bond Street region. The temporal distribution of the fringe data closely aligns with other more traditional stationer activities. Almost without execption the fringe data occurs between 1840 and 1905. As well, most of the fringe activities have a longer standing persistence at specific addresses. For example, the code *651111* is present at N029 for twenty time periods. The temporal range is from 1840 to 1935. Two distinct proprieters were located at this address during this period (Boone, Ellis). N078 has the *651111* and *651113* codes for twelve consectutive time periods (1850-1905). Only one proprieter, Masters, was located here during this time period. O033 had two fringe activities over a fourteen time period span (1840-1905). N167 also had two fringe activities over a eight time period span (1845-1880). One further point is worthy of mention on the persistence of the fringe activities. All fringe activities that persisted at a specific address for an extended time period, ie. twenty years or greater, had a change in proprieter or a change in fringe function. In fact almost all of the function changes were from the *bookseller* activity (65111*) to a *library* type of activity (651121,651122). A functional evolution of sorts is clearly displayed with the fringe retail activities.

The entire data subset of stationer related functions comprises 187 temporal occurrences at thirty-three addresses. Often in urban studies retail change occurs down a commerical ribbon rather than across it. To see if this process was valid for the stationer data two views were created illustrating each side of the street. Figures 6.9 and 6.10 present these views. The only distinguishing feature of these views is that the east side of the street has twenty-one addresses while the west side of the street has only twelve addresses. No identifiable pattern is evident for the type of stationer activities on either side of the street, or with respect to the temporal distribution attributed to each side. No distinct conclusions can be made in this regard. As well, the graphic products do not provide any statement on the urban process of *agglomerating localized economies* that is often found along urban retail ribbons, except to say that a general clustering occurs along the north end of the street. [56]

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[56] *Agglomerating economies* is the term given to establishments or functions of the same business type that tend to cluster or agglomerate in specialized areas

Figure 6.9. YEARLY ESTAB : Stationer Categories 1 - 6

651131 Stationer

651115 651116 651132 Bookseller / Stationer

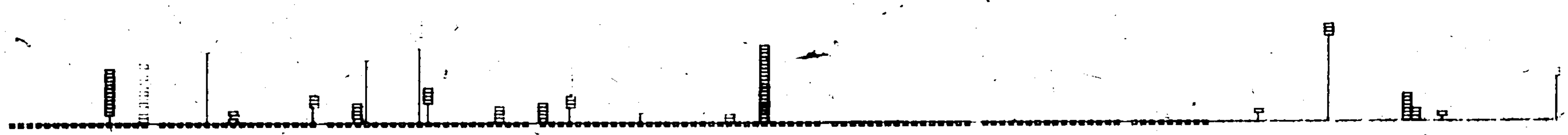
651135 Printer / Stationer / News Agent

579110 Office Furnishings

651134 Stationer / Dresscase Maker

651111 - 651114 Bookseller / Library

651121 - 651122 Library



N

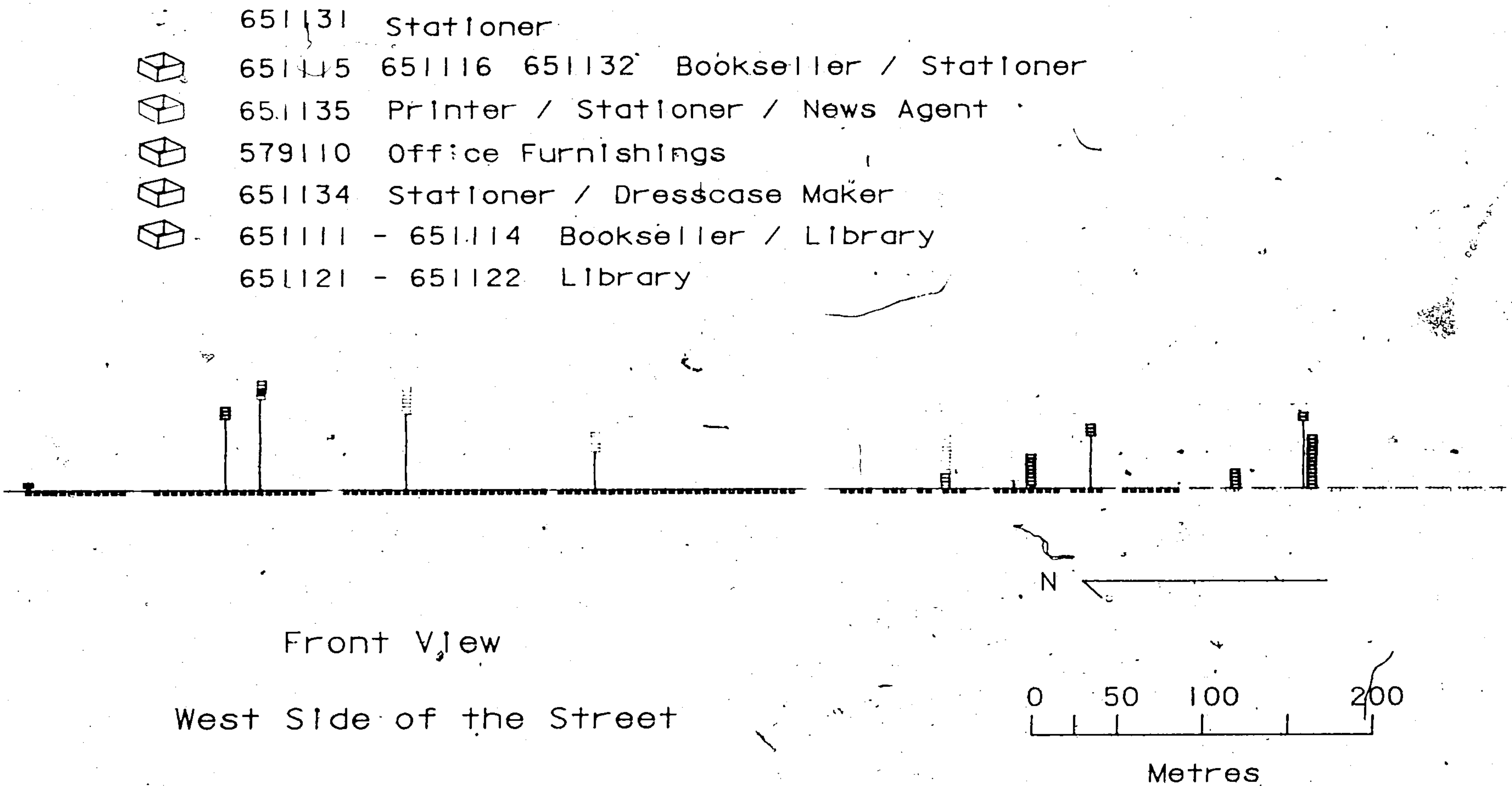
Front View

East Side of the Street

0 50 100 200

Metres

Figure 6.10. YEARLY ESTAB : Stationer Categories 1 - 6



Front View

West Side of the Street

A smaller window as illustrated in Figure 6.11 provides a more detailed look at the functional clustering at the north end of the street. All of the stationer activities are present here. Several items should be noted. First, the scene is dominated by strict stationer activities. The longest standing stationer on the street, Smythson, is present at three different addresses. As well, Smythson is one of the few occurrences that has persisted after the 1840 to 1905 time period. Most of the other stationers existed primarily during this early period. The distribution is almost entirely pre-1905. Secondly, several addresses occur that have more than one kind of stationer function present over time. The address N044 evolved from a *printer / stationer / news agent* function to a strict stationer activity. A change in proprieter also occurred here. The address N064 evolved from a *bookseller / stationer* to a strict stationer. However, activities were only present for four time periods and involved a proprieter change during that time. Note that both of these changes were to the traditional stationer activity.

The address N106 also involves some activity change. One proprieter, Ryman, is present for all the five time periods. This occurrence differs from the other functional changes in that it has occurred since 1960, and like Smythson is present on the street today. Ryman has changed from a stationer to an *office furnishings* activity. This follows the notion of the traditional stationer evolving into a more contemporary function as a office furnisher and supplier. However, this appears to be the only occurrence that supports the idea of functional evolution with respect to contemporary activities within the stationer realm.

6.1.2 AVG-LENGTH : Old Bond Street

The second graphics processing option within UMIS is AVG-LENGTH. AVG-LENGTH calculates the average length of stay of all classification codes for all addresses, and displays the average value as a cell pillar for user defined addresses. An area of interest identified by the urban specialist involved the turnover of retail activities

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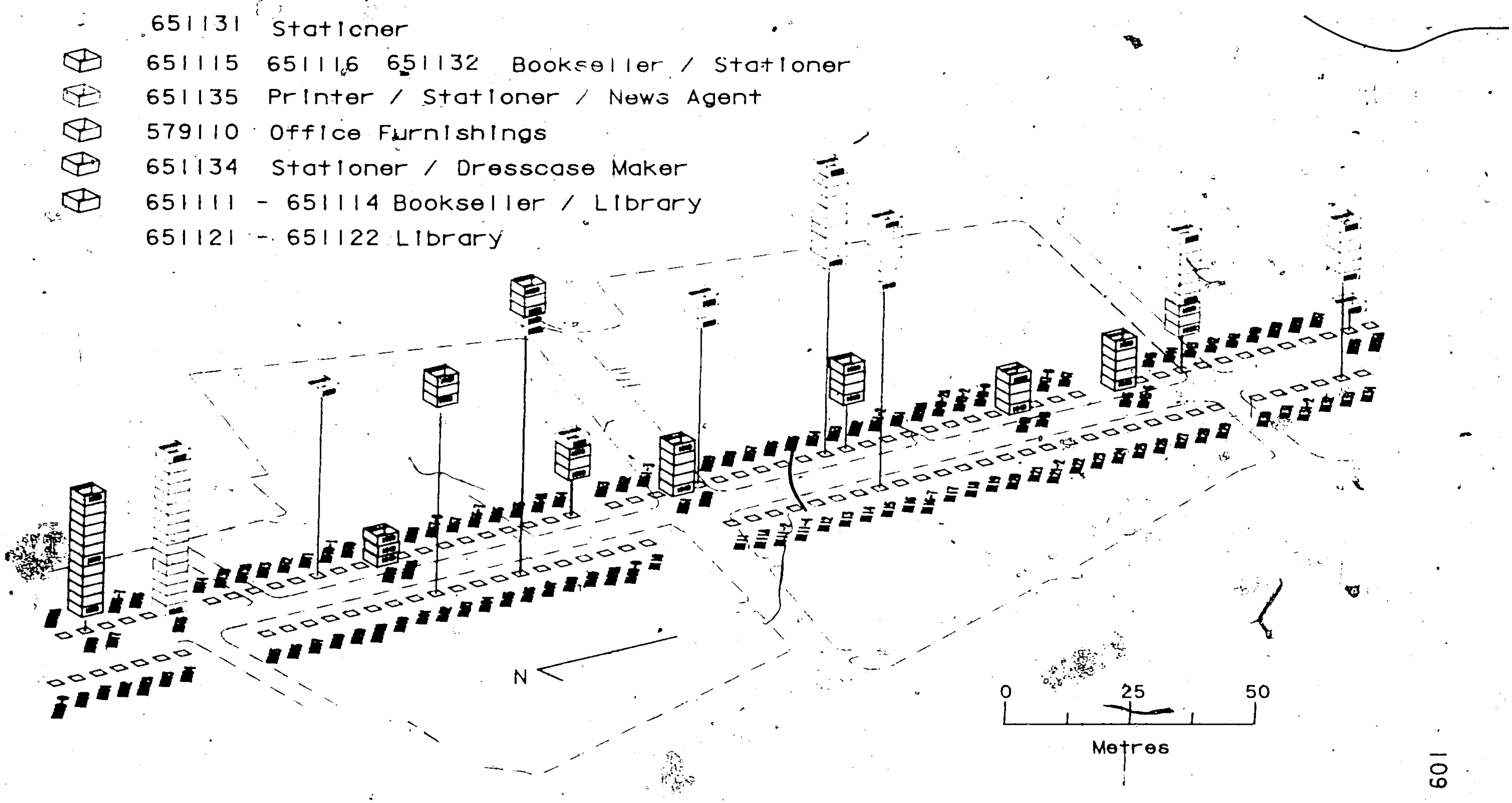
[56](cont'd) or along specific urban ribbons. Regardless of specific functional type the concentration of establishments are held together by close linkages between each other. The locational effects of the forces of scale economies allow the business types to be able to take advantage of the economies of operation that would be denied if they were located apart (Yeates, Garner, 1976, P.118-120, 278-283).

Figure 6.11. YEARLY ESTAB . Stationer Categories 1.- 6 Zoom



on Old Bond Street. Old Bond Street is the older portion of Bond Street located at the south end of the street.

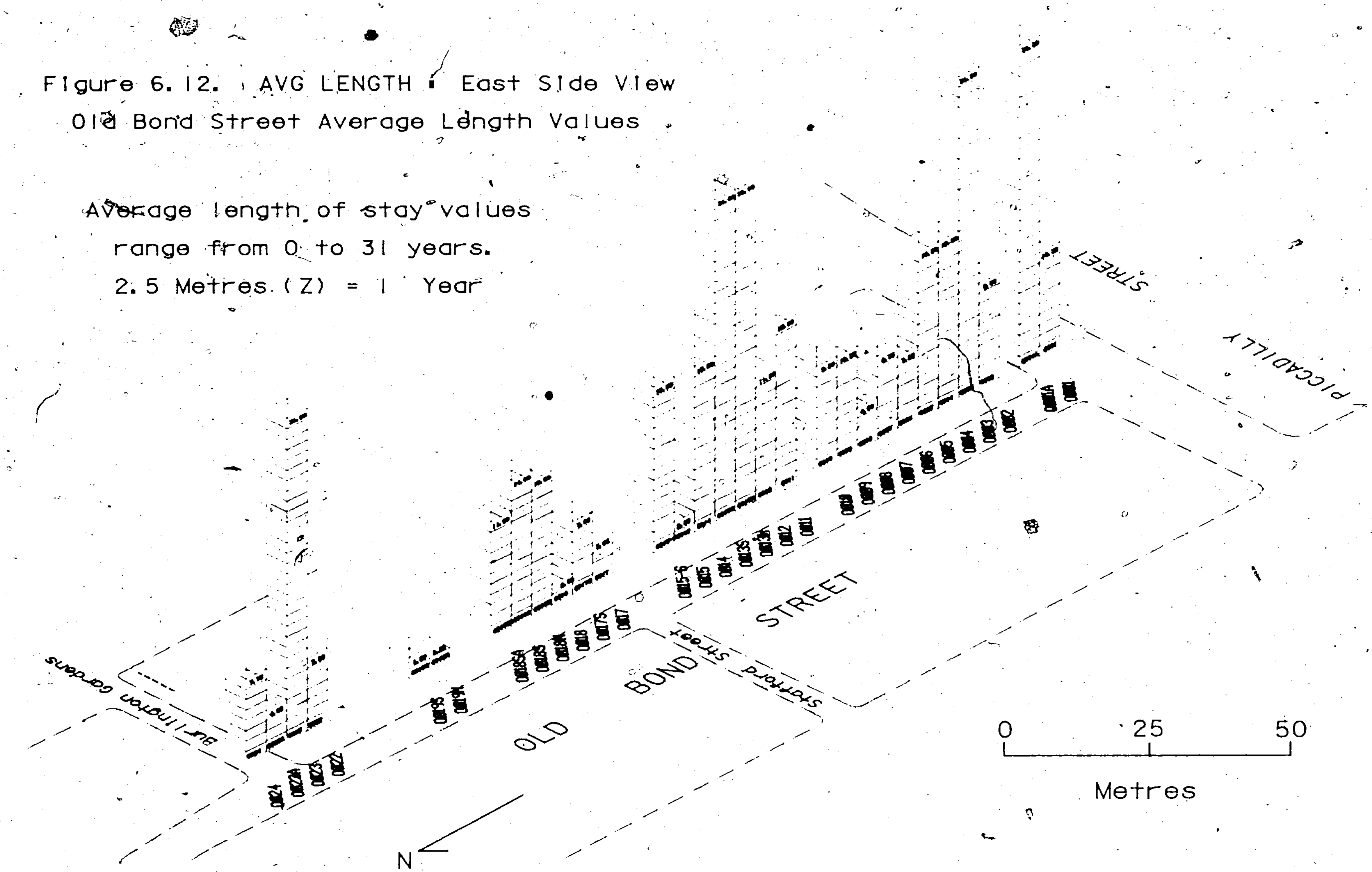
Due to the averaging technique used the AVG-LENGTH procedure is only valid for data sets that do not exceed two years in yearly interval. Using data with an interval greater than two years introduces too many unknown quantities which ultimately may result in unconfirmed and often meaningless results. Accordingly, the one year data set ranging from 1950 to 1980 was utilized for this example.

The first step in the AVG-LENGTH program is to calculate the average length of stay values. The AVG-USE routine is used to process the entire data set in this manner. A total of 234 addresses are present in the one year data set. Fifty-four are present on Old Bond Street. The AVG-USE routine creates a statistical report on the addresses and their average values. This report identifies the distribution of average values for each address as well as statistics on the number of years and the number of functions for each address. The Old Bond Street distribution has thirteen occurrences where that average length of stay value is thirty-one years. This indicates that one function was present at these addresses for the entire time period of the data set. These addresses comprise twenty-four percent of the Old Bond data subset. As well, twenty-two addresses have average length of stay values between ten and twenty-five years. Nineteen addresses have average values less than ten years, however nine of these are at addresses where establishments were only present for a few years, ie. less than ten years. Overall, the statistics indicate that the turnover of functions on Old Bond Street is relatively low. The average length of stay of all functions for all of Old Bond Street is 12.68 years. This indicates that the average length of time any function was located on Old Bond Street over the entire time period was approximately thirteen years.

Graphic representations were created using the AVG-PILLARS option of the AVG-LENGTH program. For ease in viewing and manipulation the Old Bond Street data subset was divided into two groups. Group one contains data for the east side of the street while group two contains data for the west side of the street. Of the fifty-four addresses on Old Bond Street thirty are located on the east side of the street. Accordingly, twenty-four addresses are located on the west side of the street. Figure 6.12 illustrates the distribution of average values along the east side of the street from

Figure 6.12. AVG LENGTH : East Side View
Old Bond Street Average Length Values

Average length of stay values
range from 0 to 31 years.
2.5 Metres (Z) = 1 Year



an isometric view. No distinct pattern is noticeable in this distribution. There are five occurrences where the average value is thirty-one years. These functions have persisted at a specific address for the entire time period. No real distinct spatial pattern exists within the five persisting addresses. The high order nature of the retail functions reflects the traditional image of Bond Street. Two art dealers are among the persisters, as well as an optician, a hair stylist, and the original Benson & Hedges cigarette maker and tobacconist. Figure 6.13 presents the east side of the street from a frontal perspective. Exact addresses are located at the bottom of the cell pillars while the average value is located at the top of the pillar.

Figure 6.14 illustrates the distribution of average values along the west side of the street from an isometric view. Again there is no disinct pattern to the distribution of the average values. However, there are eight occurrences where the average length of stay value is thirty-one years. Some clustering occurs in the spatial pattern of these persisters towards the centre of the street. Three are located at 0043, 0044, and 0045; three are located at 0034-6, 0038, and 0039; and two are located at 0029 and 0030. Similar to the east side of the street the high order nature of the retail functions does indeed reflect the traditional image of Bond Street as a high class shopping street. Of the eight persisters two are banking institutions; three are jewellers; one is an art dealer; one is an amber specialist; and one is a shoe and boot shop. The shoe and boot retailer is the only persister that maintained function but changed proprieters over the entire time period. All other persisters, on both sides of the street, only had one proprieter. Figure 6.15 presents the west side of the street from a frontal perspective.

6.1.3 DUR-FUNCTION : 100 Year Persistence

The third graphics processing option within UMIS is DUR-FUNCTION. DUR-FUNCTION calculates and displays the duration in years that an activity has been at an address. This identifies the persistence of activities for specific addresses. The area of particular interest to the urban specialist in this example involves the identification of retail establishments that have persisted for over 100 years on Bond Street. Four types of retail persistence are identified by Johnson (1986). **Activity** persistence is the duration of identical SIC codes at a given address over a specific time period. No

Figure 6.13.AVG LENGTH : Old Bond Street Average Length Values
East Side View - Frontal Perspective

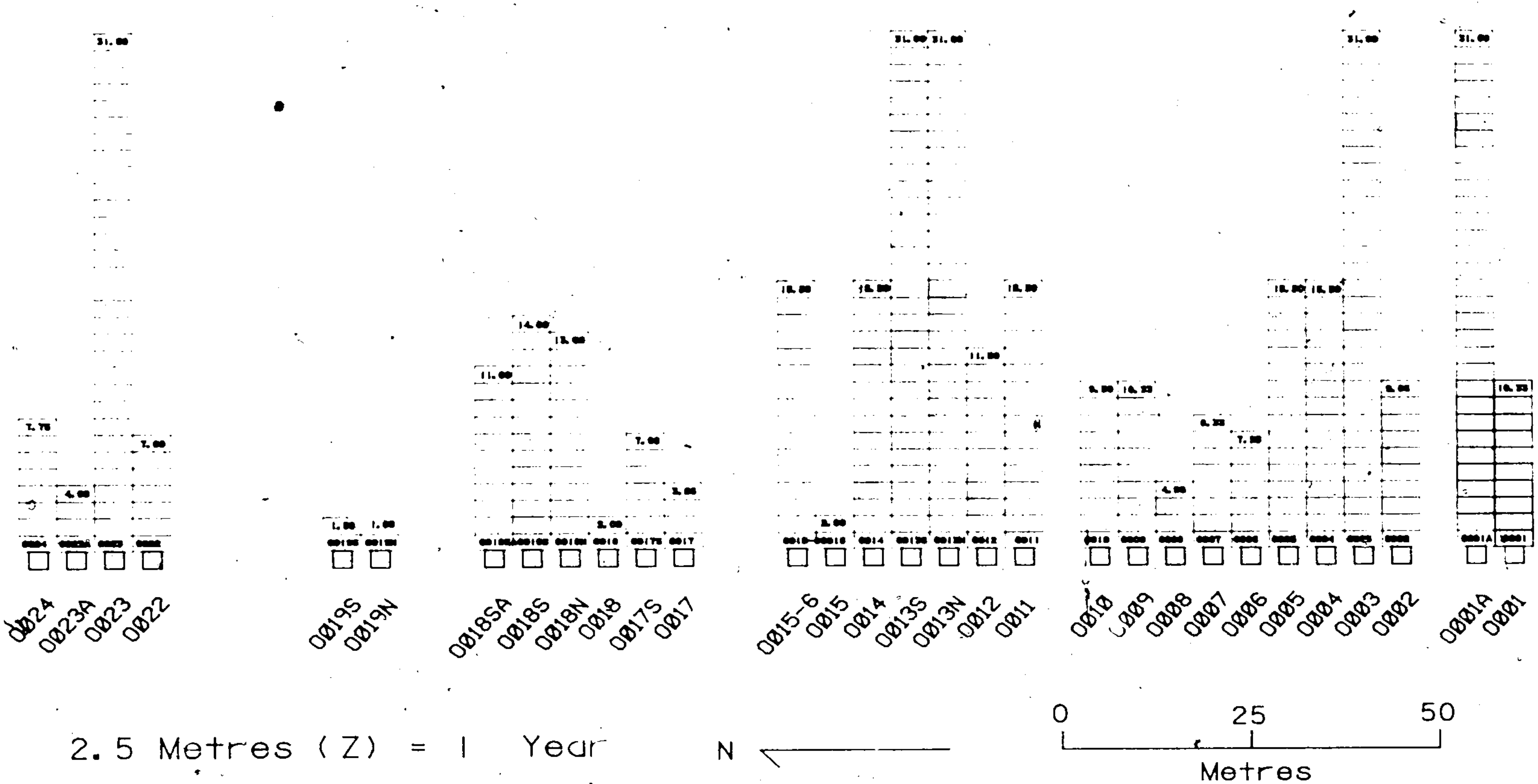


Figure 6.14. AVG LENGTH : West Side View
Old Bond Street Average Length Values

Average length of stay values
range from 0 to 31 years.
2.5 Metres (Z) = 1 Year

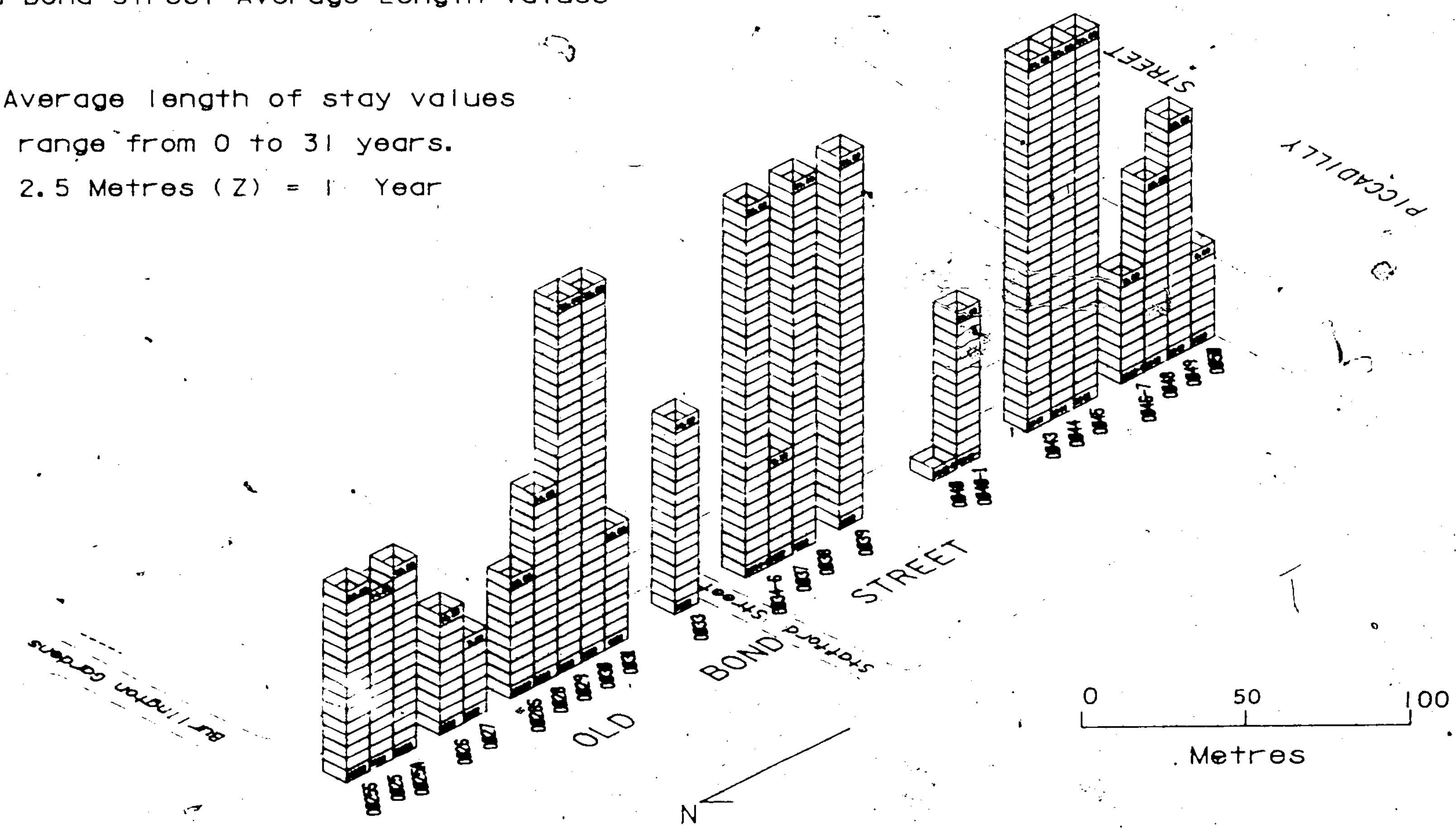
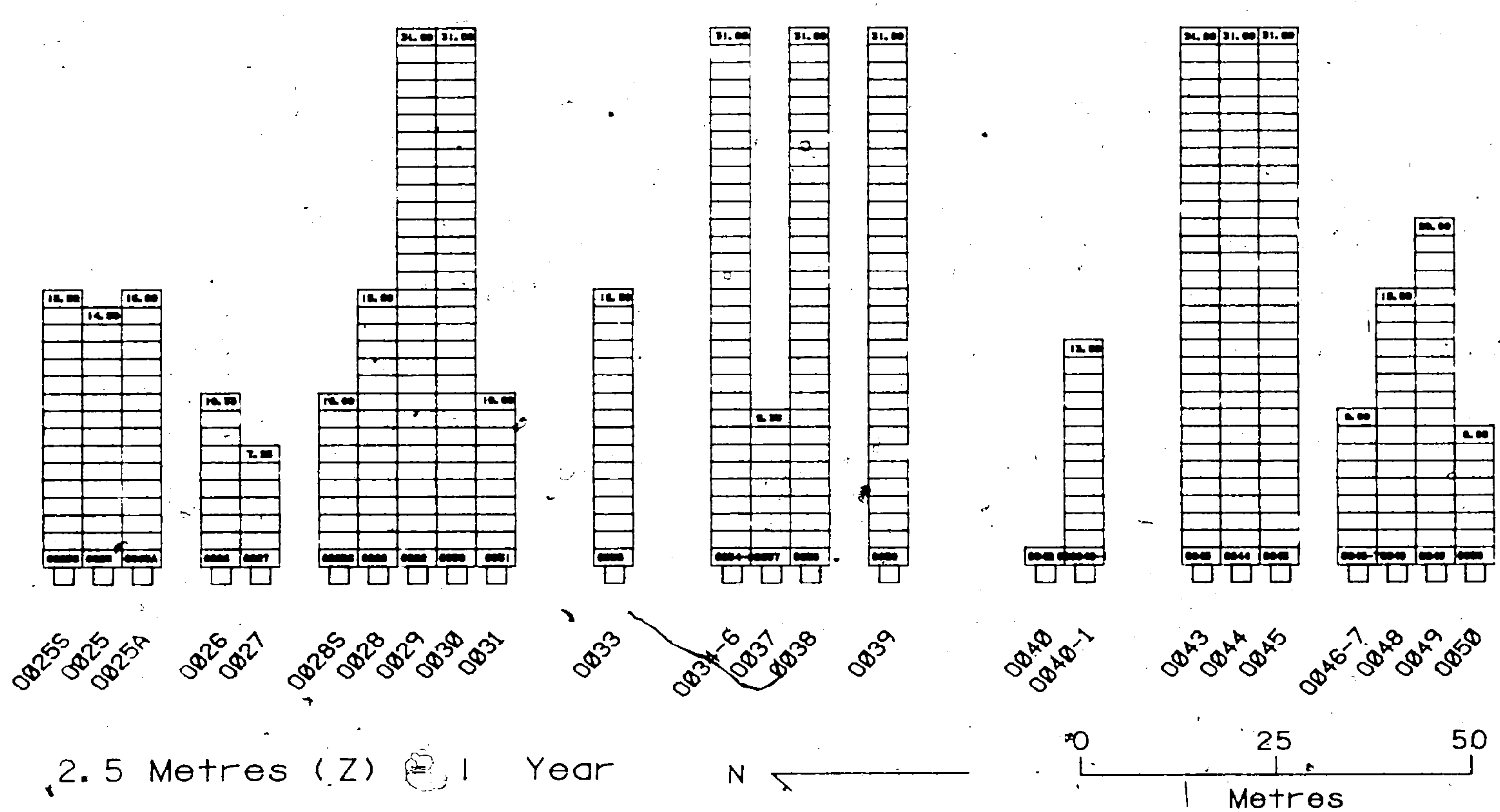


Figure 6.15. AVG LENGTH : Old Bond Street Average Length Values
West Side View - Frontal Perspective



change in SIC or address migration occurs. **Adaptive** persistence occurs when a firm maintains one particular address but changes use. **Firm** persistence is present when a firm remains on the street but changes address. No change in code occurs. **Both** persistence exists when a change in location and code occurs. The identification of addresses for input into the DUR-FUNCTION program is based on the four types of persistence.

The routine PERSIST was written to support the identification of persistence for any retail data set. The level of persistence in years is defined by the user at the time of operation. A 100 year delimiter was used for this example. The PERSIST routine generates two types of reports, tabular and graph. The tabular report identifies the specific firm which has persisted, as well as the persisting addresses, their relevant time frame, the number of time intervals, the SIC codes, and the kind of persistence that occurs. The persistence graph presents a graphic representation of the temporal extent of a particular firm augmented by statistical totals on the number of yearly intervals, the number of duplicate years, the number of different SIC codes, and the number of different addresses. Both reports serve as clear delimiters of the spatial extent of the data subset to be used during a DUR-FUNCTION program run. For the Bond Street five year data set fifteen firms were identified as having a persistence of 100 years on the street. Five firms were identified as *active* persisters (no change), three as *adaptive* persisters (address change), two as *firm* persisters (code change), and five as *both* persisters (address and code change). Twenty-three different addresses were identified. Figure 6.16 is the tabular report created for the Bond Street five year data set based on a 100 year persistence level. Figure 6.17 is the graph report created for the Bond Street five year data set based on a 100 year persistence level.

The first step in the DUR-FUNCTION program is to calculate the duration values. The DUR-CRE routine is used to process the entire data set in this manner. A total of 310 addresses are present in the five year data set. Duration values are calculated for each address.

The data subset selection criteria was defined by using the addresses and yearly extents from the tabular report. Graphic representations were created using the DUR-PILLARS option of the DUR-FUNCTION program based on this selection criteria.

Figure 6.16. One Hundred Year Persistence Tabular Report
Firms are in alphabetical order

"ACTIV" indicates ACTIVITY PERSISTENCE (no change)
"FIRM" indicates FIRM PERSISTENCE (location change)
"ADAPT" indicates ADAPTIVE PERSISTENCE (code change)
"BOTH" indicates both FIRM and ADAPTIVE PERSISTENCE (change in location and code)

Firm Name	Address	Years	Intervals	Codes	Type
1. Firm = ASPREY					
ASPREY	N165-9	1850-1980	27	651131 656184 656185 656124	ADAPT
2. Firm = BEALE					
BEALE & INMAN	N131-2	1840-1980	29	612110	ACTIV
3. Firm = BENSON					
BENSON	O025	1870-1970	21	656161	ACTIV
4. Firm = BESON & HEDGES					
BENSON & HEDGES	O013S	1875-1980	22	659921	ACTIV
5. Firm = CHARBONNEL & WALKER					
CHARBONNEL	N173 O031 O028S	1880-1910 1915-1975 1980-1980	7 14 1	601262 601261 601261	BOTH
6. Firm = DIXEY					
DIXEY	N003	1840-1925	18	659210 659212 659210	BOTH
DIXEY	O019	1930-1940	3	659210	

Figure 6.16. Continued ...

Firm Name	Address	Years	Intervals	Codes	Type
7. Firm = HILHOUSE					
HILHOUSE	N011	1840-1840	1	615230	BOTH
HILHOUSE	N011	1845-1970	26	615211	
HILHOUSE	N012	1840-1845	2	617420	
8. Firm = HOOK & KNOWLES					
HOOK & KNOWLES	N066	1845-1945	21	618222 618212	ADAPT
9. Firm = HUNT & ROSKELL					
HUNT & ROSKELL	N156	1845-1975	14	656124	BOTH
HUNT & ROSKELL	O025A	1915-1965	11	656124 656111	
10. Firm = NATIONAL LINEN CO					
NATIONAL LINEN	N130	1860-1975	24	617100	ACTIV
11. Firm = ROBERTS					
ROBERTS	N007	1840-1840	1	603410	BOTH
ROBERTS	N009A	1860-1880	5	618212	
ROBERTS	N076	1875-1960	18	603100	
12. Firm = SAVORY & MOORE					
SAVORY & MOORE	N143	1840-1980	29	603100	ACTIV
13. Firm = TESSIERS					
TESSIERS	N026	1855-1980	26	656122 656121 656124	ADAPT
14. Firm = THOMAS					
THOMAS	N153	1840-1940	21	656121	FIRM
THOMAS	O028S	1875-1875	1	656121	
15. Firm = THOS AGNEW & SONS					
AGNEW & SONS	O039BU	1880-1905	6	659311	FIRM
AGNEW & SONS	O043	1910-1980	15	659311	

Figure 6.17. One Hundred Year Persistence Graph Report
Firms are in alphabetical order

\+ indicates 2 addresses were present for 1 firm in 1 year.
& indicates 3 addresses were present for 1 firm in 1 year.
Incremental numbers in the graph represent a change in address.

"In" represents number of yearly intervals
"Yrs" represents total years
"D" represents total years with duplicate addresses
"A" represents number of different addresses

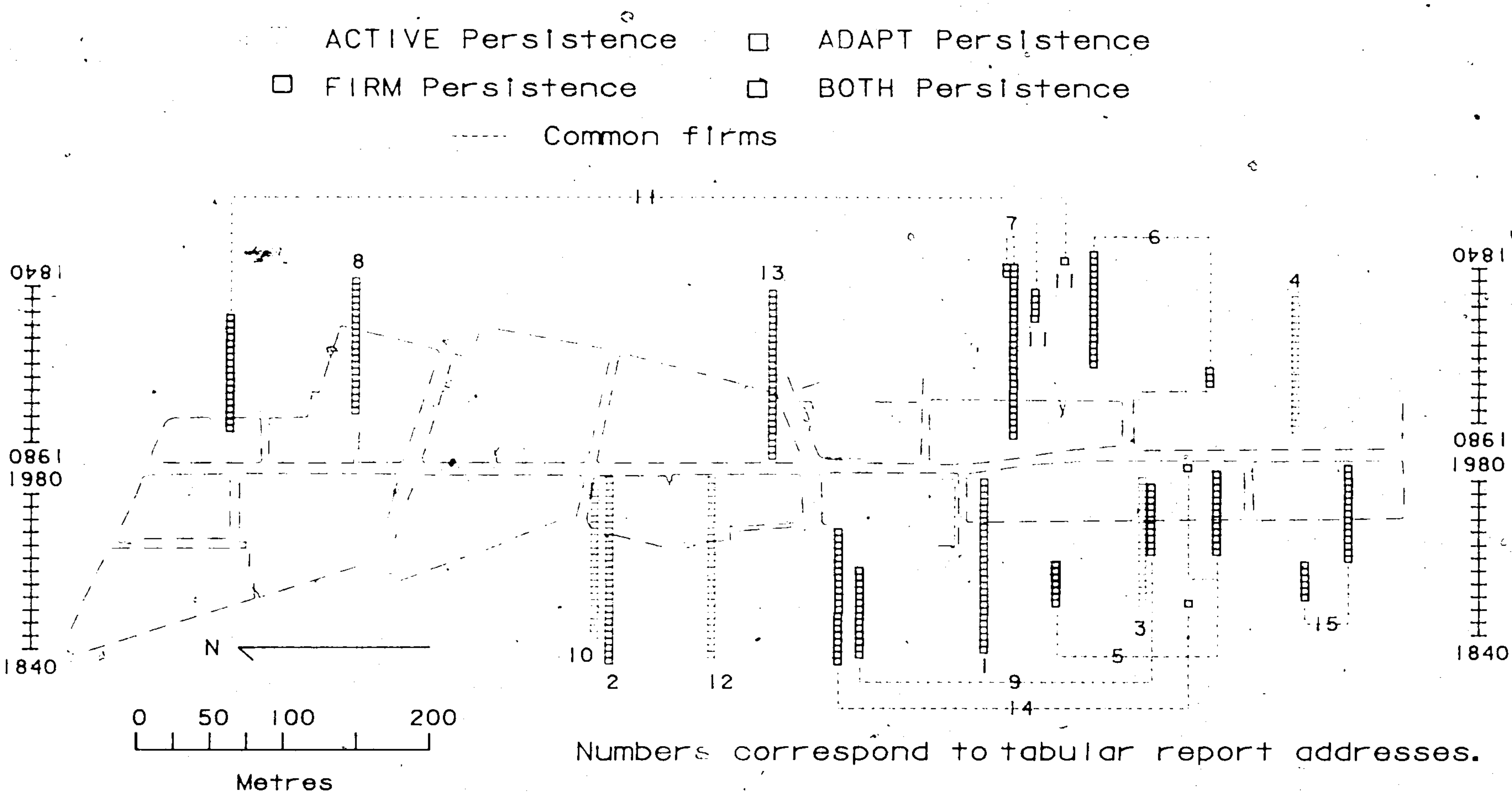
Firm Name	1840 — 1980 000000000000000	In	Yrs	D	C	A
ASPREY	111111111111111111111111111	27	130	0	4	1
BEALE	11111111111111111111111111111	29	140	0	1	1
BENSON	111111111111111111111	21	100	0	1	1
BENSON & HEDGES	1111111111111111111111	22	105	0	1	1
CHARBONNEL	111111222222222222223	21	100	0	2	3
DIXEY	111111111111111111222	21	100	0	3	2
HILHOUSE	++1111111111111111111111111	27	130	2	5	1
HOOK KNOWLES	111111111111111111111	21	100	0	2	1
HUNT & ROSKELL	1111111111111222222222222	25	120	0	2	2
NATIONAL LINEN	111111111111111111111111	24	115	0	1	1
ROBERTS	1 222++3333333333333333	22	105	2	5	3
SAVORY & MOORE	11111111111111111111111111111	29	140	0	1	1
TESSIERS	11111111111111111111111111	26	125	0	3	1
THOMAS	1111111+1111111111111	21	100	1	1	1
AGNEW & SONS	111111222222222222222	21	100	0	1	2

Different coloured cells were placed for each type of persistence. Figure 6.18 illustrates the planimetric view of the duration values for firms that have persisted for 100 years or more. The east side of the street is comprised of ten addresses. These are evenly distributed down the street. No *firm* persistence exists on this side of the street. The west side of the street has fourteen addresses. All four types of persistence are present. These addresses are clustered towards the south end of the street. A noticeable spatial pattern is that four of five *active* persisters are located on the west side as well as both *firm* persisters. The perspective views presented in Figures 6.19 and 6.20 illustrate this spatial distribution. One perspective is presented from each end of the street to account for the view blockage that occurs with this type of three dimensional display. The blockage of features is directly related to the form of the presentation and the content of the particular data subset.

The other notable spatial pattern involves the firms that have migrated to new addresses. The address changes that occurred for *firm* and *both* persisters did so on the same side of the street. No address migration occurred across the street. Of the two *firm* occurrences only one involves a valid address change. This was Thos. Agnew and Sons which moved from 0039 (1905) to 0043 (1910). The other circumstance of *firm* persistence merely involves a duplicate location for a firm for one time period. While the code is the same further investigation may provide evidence of a miscoding with respect to the firm name, address or SIC code. Within the five *both* occurrences three involved valid address migrations on the street. All three circumstances also included minor SIC code changes, ie. Hilhouse (hatters glovers/615230) to Hilhouse (hatters/6152[illegible]).

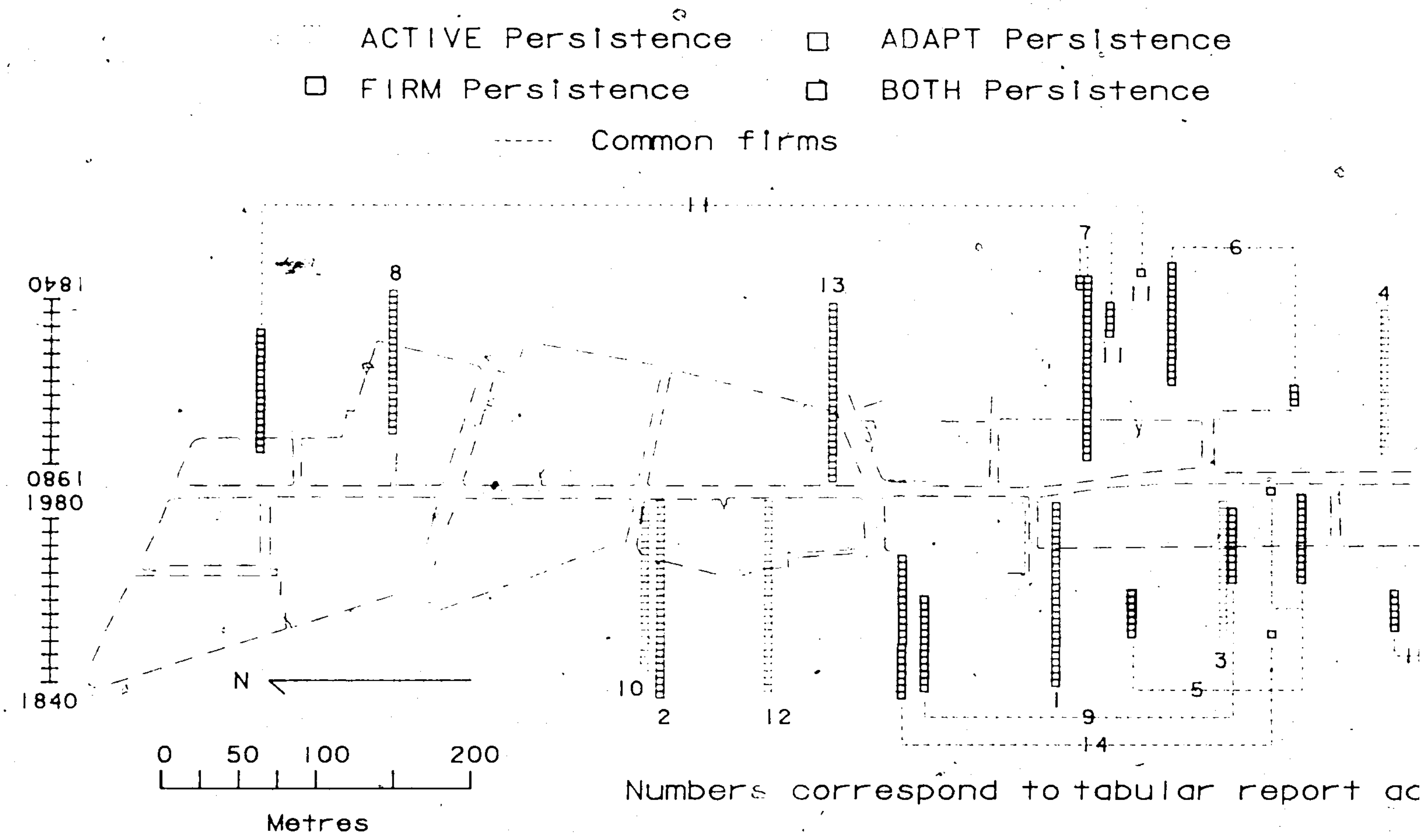
The firm Roberts poses a more interesting interpretation. Three addresses are present during the persistence period. Two of the addresses, N09A and N076, are present from 1875 to 18[illegible]0. These addresses also provide the greatest distance in terms of address migration. This is complicated by the fact all three addresses have distinctly different SIC codes. They range from being a *perfumer*, to a *shoe and boot maker*, to a *chemist*. There is no obvious correlation between the address changes or the code changes. This pattern indicates that there may be an error in the coding of the data items. Use of a common firm name is an obvious culprit. An investigation into the

Figure 6.18. DUR FUNCTION : Firms With 100 Year Persistence Planimetric View,



Numbers correspond to tabular report addresses.

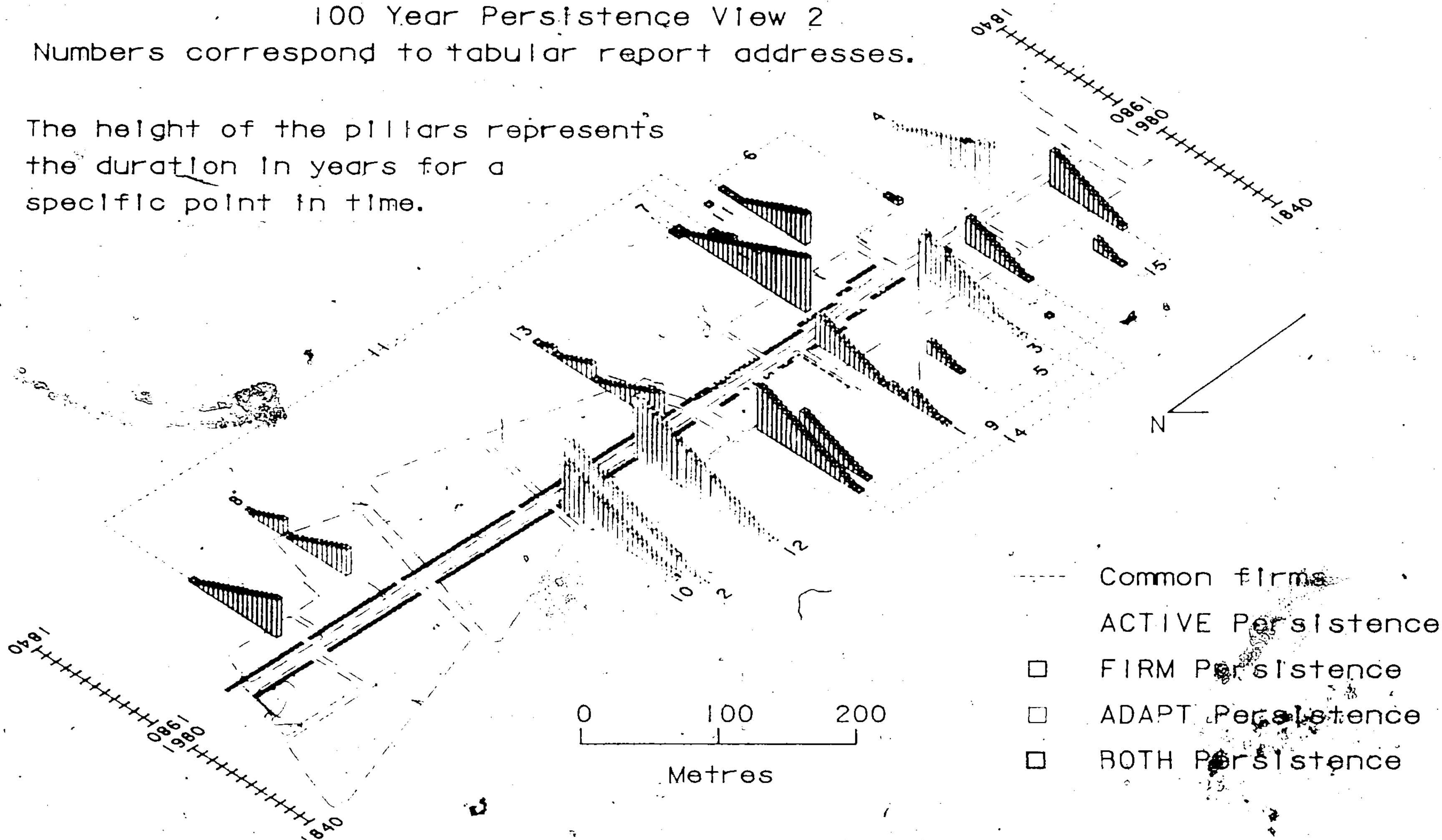
Figure 6.18. DUR FUNCTION : Firms With 100 Year Persistenc
Planimetric View,



Numbers correspond to tabular report ac

Figure 6.20. DUR-FUNCTION
100 Year Persistence View 2
Numbers correspond to tabular report addresses.

The height of the pillars represents the duration in years for a specific point in time.



data source may help determine the uniqueness of this situation.

The final occurrence of a **both** persister does not really include an address migration. The firm Hilhouse has duplicate addresses for the years 1840 to 1845. However, these addresses are side by side, N011 and N012 respectively, and both have somewhat related functions, ie. *linen maker*/617420 and *hatter*/615211. It appears that this firm merely had two stores for a short time period. The nature of the data source, ie. ground floor uses only, makes it difficult to substantiate these observations. Further investigation into other data sources may help to determine the validity of such a conclusion.

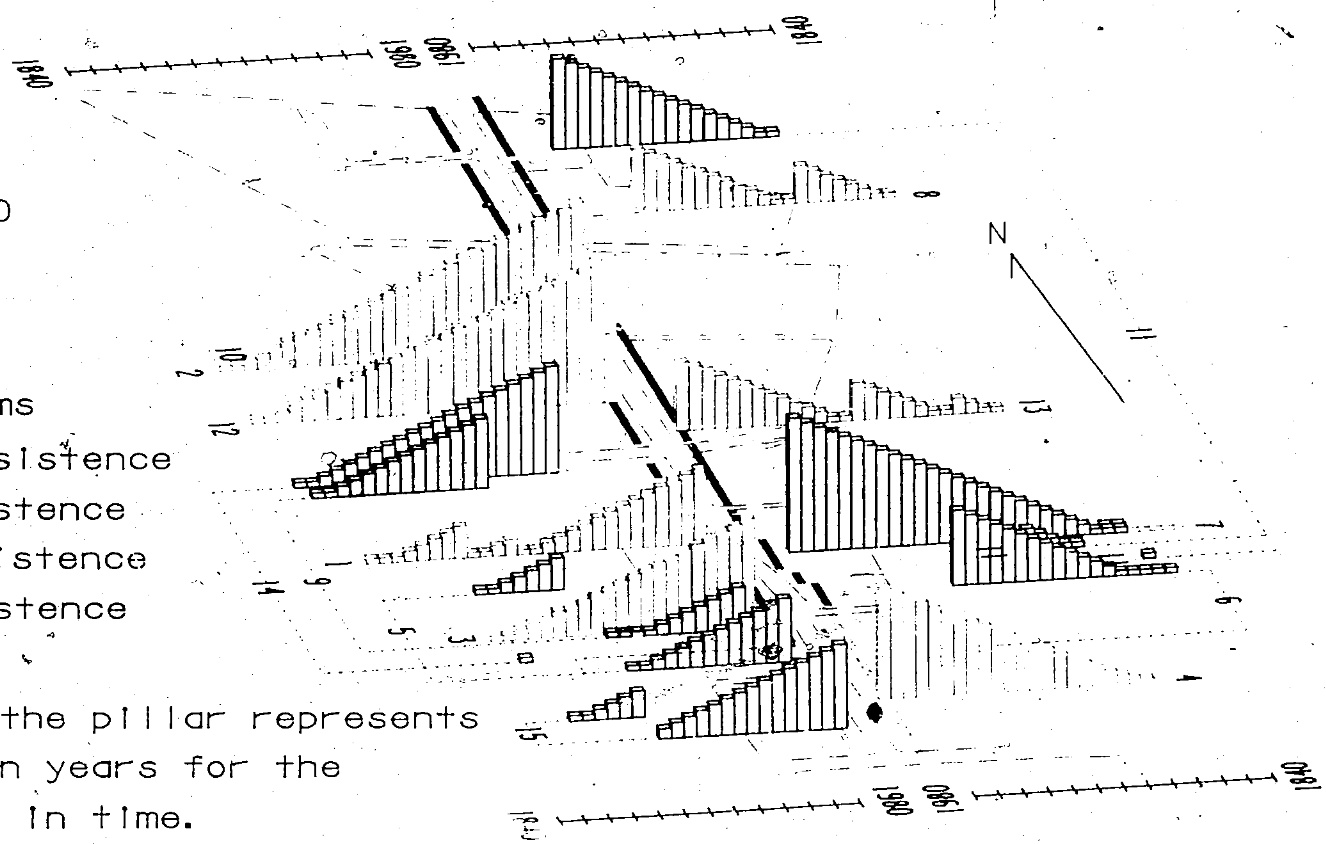
Of the fifteen persisting firms five illustrate strict **activity** persistence. While all serve specialized retail functions no functional pattern is evident. It should be noted that two of these firms are the longest standing establishments on Bond Street. Both have been resident on Bond Street at one location for over 140 years. Beale and Inman (N131-2) are a *high fashion mens store* and Savory and Moore (N143) are a *traditional chemists*. The two **firm** persisters are too few in number and too diverse in function to indicate any trend in their type of persistence. The three **adaptive** persisters however, all show a consistent trend in their code changes. In particular, Asprey and Co. (N165-9) appears to have evolved from being a traditional *stationer* (651131) to a *dressing case maker* (656184) and *dressing and writing case maker* (656185), into a present day *jeweller, goldsmith and silversmith* (656124). A retail development is obvious. The other two **adaptive** persisters involve minor code changes that tend to indicate a gradual retail development in a more contemporary manner. One of these, Tessiers (N026), also provides a *jeweller, goldsmith and silversmith* function (656124). Figure 6.21 clearly illustrates the duration of functions at the persisting addresses. Note the longer duration of the final codes found for the **adaptive** persisters. Each extends for at least twelve time periods. The earlier functions are all quite short in duration.

Figure 6.21. DUR-FUNCTION : 100 Year Persistence View 3

Numbers correspond to tabular report addresses.

0 50 100

Metres



---- Common firms

- ACTIVE Persistence
- FIRM Persistence
- ADAPT Persistence
- BOTH Persistence

The height of the pillar represents the duration in years for the specific point in time.

6.2 Practical Considerations

6.2.1 Cartographic Components

The cartographic components of the various map products presented in this thesis were all designed with respect to the qualitative nature of the data set. UMIS utilizes *geometric* symbols in the representation of point data. Nominal differentiation is achieved by using *shape* and *colour*. These cartographic visual variables are the predominant symbol dimensions used in mapping qualitative point data.

The map products presented in Chapter VI utilize the most common geometric shape, the square. The UMIS software allows the user to define another point symbol if desired. However, the operating characteristics ensure that shape is maintained for each map product. Equality in shape is preserved across data classes. The square symbology was used for the three examples because it reflects the stepped nature of the data set, as well as symbolizing the appearance of buildings and establishments on a retail ribbon. This results in a comfortable display that is aesthetically pleasing. The appearance of textual information is also more aesthetic on a flat surface.

Colour is used as a secondary dimension for the differentiation of the data. The YEARLY-ESTAB program in particular utilizes colour as a dominant display variable. Colour is commonly used to distinguish the qualitative attribute in a nominally scaled data set. YEARLY-ESTAB uses colour to identify the different retail activity for specific addresses. Six different categories of retail activity are identified. A different colour coded cell was placed for each category. AVG-LENGTH uses colour to merely distinguish sides of the street. Due to the nature of the analysis colour is not required for any differentiation between items. DUR-FUNCTION uses colour to distinguish different kinds of retail persistence. The colour of the cell at a particular address determines the persistence process that existed.

The other visual variables of *direction, pattern,* and *value* are not utilized with the UMIS displays. As well, the dimension of *size* is determined by the density of data locations for the entire data set. *Value* is generally considered to be the most significant dimension in colour on a map, however it has traditionally been used with quantitative data sets. The choropleth map is a classic example. Since our data set is qualitative in nature and the use of variation in value generally conveys an implication of magnitude, the variable of value has not been employed.

Map clarity has always been a concern when dealing with 3-D graphic representations. The use of point symbols instead of 3-D volumes has provided a clearer, less hidden depiction. The blockage of thematic features on the maps is relatively low. Some view blockage does occur due to the long, linear nature of the street. This is especially noticeable in the AVG-LENGTH maps where each side of the street had to be presented individually. However, all the graphics processing algorithms are oriented towards using data subsets of a relatively small size. With this context in mind map clarity is usually not a problem.

Akin to the idea of map clarity and view blockage is the notion of dynamic viewing and 3-D visual characteristics. As previously noted, the map product created within UMIS is designed around viewing in an interactive, dynamic mode. They are not developed for final hardcopy presentation. The use of the map as a temporary product during the investigation and analysis of a research theme is paramount. However, some problems did occur in the dynamic viewing of the map products. Technological constraints limited the extent of a data subset that could be viewed dynamically. These limitations were not conceptual in nature but purely technical. Appropriate hardware and software does exist which easily removes these current processing problems.

The three visual characteristics identified in Chapter II, namely *viewing azimuth*, *elevation angle*, and *vertical exaggeration* are no longer concerns with respect to map clarity and view blockage. Both viewing azimuth and elevation angle can be determined interactively during dynamic viewing. Vertical exaggeration must be defined during the map creation process. A sound knowledge of the data content and distribution is helpful in determining an appropriate exaggeration factor. Both the AVG-LENGTH and DUR-FUNCTION processing required duplicate runs to achieve the proper viewing exaggerations for the specific data subsets.

Some interactive editing was required on the map products to achieve satisfactory graphics for hardcopy presentation. All map legends and titles were created interactively by the author. As well, all maps required processing with the Intergraph Hidden Line Removal (HLIN) software to obtain a clear representation that was free of hidden map features. The current limitation with this software process is that no view manipulation can be done to the map product after hidden line removal is complete. The view becomes static losing all the advantages of dynamic viewing. A brief review of the technical observations from the three examples is appropriate.

6.2.2 Technical Observations

Technical observations from the three graphic examples include a review of the elapsed and CPU processing times as well as output file sizes. The YEARLY-ESTAB example involved four processing runs with the UMIS software. The CODE-SELECT routine was used to extract a data subset for the stationer activity. This activity took 14.95 seconds of CPU time to complete. The output file size of the data subset was 0.01 megabytes (24 blocks). [57] Three processing runs were required of the ESTAB-PILLARS program to create the map products. When combined these runs took only 13.74 seconds of CPU time and only four minutes and thirty-two seconds of elapsed time. All processing was done in an interactive mode. In total 187 cells were placed in three design files. The three design files are 0.23 (465 blocks), 0.15 (399 blocks), and 0.26 (510 blocks) megabytes in storage space. These files are relatively small in size compared to standard design files used in base mapping and other thematic applications.

The AVG-LENGTH example involved three processing runs with the UMIS software. The AVG-USE routine was used to calculate the average length of stay values for the entire data set. This process required only 3.81 seconds of CPU time. The output file size was 0.138 megabytes (27 blocks). AVG-PILLARS was used to create the map products. One processing run was needed for each side of Old Bond Street. In total, 821 cells were placed at 54 addresses using only 15.23 seconds of CPU time. The output design files are 0.43 (834 blocks) and 0.46 (903 blocks) megabytes in size. All processing was done in an interactive mode.

The DUR-FUNCTION example involved multiple program runs to satisfy the distinct selection criterias identified by the PERSIST routine. The DUR-CRE routine was

[57] The notation of *blocks* is used by the VAX/VMS operating system to designate storage space. A block is equal to 512 bytes.

used to calculate the duration values for the entire data set. This initial process required one minute and two seconds of CPU time to complete. Clearly this data manipulation process is more intensive that the other two examples. The DUR-PILLARS program was used to create the map products. In total twenty-six graphics processing runs were required. This necessitated that all processing be done in batch mode. Four design files were utilized, each representing a different type of persistence. A total of 13 minutes and 24.61 seconds of CPU time were required to place all the graphic elements. This time is much higher than the other two examples. This is most likely due to the processing logic of the DUR-PILLARS program. The checking of all input records against the user defined selection criteria occurs in this module. The elapsed time for this processing was 59 minutes and 28.15 seconds.

The processing times are not reflective of the output data file sizes. Output files are relatively small in size. With such high processing times one would expect large design files with many elements placed. This is not the case. The output design files are 0.29 (573 blocks), 0.24 (462 blocks), 0.27 (537 blocks), and 0.21 (411 blocks) megabytes in storage space.

In summary this chapter has presented three urban mapping examples as identified by the urban specialist. Each has utilized the specific software that was developed within the context of the Urban Mapping Information System. A brief overview of the cartographic components and technical observations of the examples was given. Chapter VII will supplement the case study examples by evaluating the research with respect to the goals as identified in Chapter I. Final conclusions will be presented.

7. EVALUATION AND CONCLUSION

The final chapter of this thesis includes a general overview and discussion of the study process and methodology; an evaluation of the cartographic and geographic objectives of the research; and an examination of the problems and limitations that were encountered during the study process. Recommendations for future study and a summarizing statement on the role of mapping information systems and 3-D mapping techniques as a viable alternative for or as a contribution to the management of spatial data will conclude the chapter.

7.1 Overview of the Study Process

The study process was defined with respect to the four primary aims of the research. A methodical work plan was designed which would address the research objectives as well as incorporate the accepted methods of processing cartographic data. Some innovative methods for investigating retail change in the urban environment, designed by the urban specialist, were also included.

The fundamental basis of the study process is a systematic, iterative approach that presents a framework for continued data analysis. This approach was presented in Figure 3.2. The foundation of this approach lies in the application of the three basic stages of cartographic data handling as defined by Robinson et al, 1978. These are :

1. Data collection
2. Data manipulation (classification)
3. Data symbolization and display (application software development).

A brief review of the application of this approach with respect to the case study is appropriate at this time. As proposed by Robinson, the use of primary data sources collected by the specialist provides an excellent basis with which to establish a full realization of the level of reliability of the data. A clear understanding of the data's reliability is necessary when determining the appropriateness of applying various statistical measures. The data used in the Bond Street case study was primarily obtained by personal investigation. As well, a variety of secondary data sources were used to supplement the substantial information personally collected about the street. Several of these sources included interaction with an assortment of proprieters on the street.

The confidence level of the data source was especially important in determining the ground floor retail activities from the upper floor uses. Retailing functions usually exist on the ground floor of a building. Knowledge about the building located at a particular address was invaluable in determining the exact establishment location.

The *data manipulation* step involved a classification of all activities for the street addresses. The classification stage was merely an attempt to typify the data items. The classification process required modification to an existing Standard Industrial Classification (SIC) scheme. The complexities of incorporating temporal data items into a contemporary classification scheme were varied. The modified SIC was an attempt to include the characteristics of several different retail environments that occurred over time on the street. The quality of the derived classification scheme is better understood only after intensive use of the data has taken place. The approach to categorizing the data was based on solid cartographic theory, however the data processing that has been undertaken since the classification step has identified many shortcomings and inaccuracies to the point that a complete review of the SIC is appropriate. Minor modifications to the SIC were done as their need became evident.

The final step in the data handling process involved *data symbolization and display*. The design and development of application software was the main emphasis of this step. The nature of the research, spatio-temporal urban data, necessitated the development of software programs to effectively measure the data. No comprehensive software existed that could deal with the unique idiosyncrasies of a temporal urban infrastructure data set. This is primarily due to the research nature of the identified problems.

The development of the software was loosely based on the programmer's model of interactive graphics as presented by Foley and Van Dam (1982, P. 24). The model was altered slightly to incorporate the use of Intergraph's IGDS software. The use of IGDS was appropriate for effective 3-D display. This data handling step actually involved analytical processing of the encoded data set by extracting data subsets and converting these to IGDS 3-D graphic representations. Developments in the field of geographic data management since the initiation of this research have identified the need for relational data base management tools to properly incorporate the standard analytical functions that are required. The use of the IGDS interface is currently limited in this regard.

An evaluation of the specific objectives of the research is necessary. This will identify if the aims of the study were achieved as well as determine if the study process that was used was appropriate.

7.2 Evaluation of the Research Objectives

As discussed throughout this thesis there are four primary aims of the research. A review of each objective as well as an assessment of the relative success of the research in satisifying each goal is required. Each research objective is addressed in order.

As identified in Chapter I, the fundamental aim of the thesis research was to develop a mapping information system, based on the inherent advantages of using 3-D cartographic images to investigate multi-dimensional data, that would integrate and optimize the advantages of the disciplines of cartography, geography, and computer graphics. Without doubt this aim has been fulfilled. Technological developments in the computer graphics field have clearly allowed the successfull integration of cartographic methods and geographic analysis. In fact many of the mapping application developments in computer graphics software have been based on strict cartographic methodologies. The basis of developing a GIS revolves around the data handling steps proposed by Robinson. The development of GIS's is an attempt to create a comprehensive software system that includes cartographic concepts and geographic methods of analysis. The incorporation of computer graphics hardware and software technology provides the mechanism for linking the GIS together.

In the case of UMIS a successfull combination of cartographic methods of data handling and display, geographic concepts of data manipulation and analysis, and computer graphics techniques for display have been achieved. UMIS is based on software linkages to combine the approaches of each discipline. The appropriate methods required for the management of urban geographic data have been extracted from each discipline and incorporated into a unified mechanism for application.

It should be noted that computer graphics technology has also offered many new methods for display that previously were too cumbersome or impossible to achieve. The case of 3-D representations is a excellent example. As shown in the UMIS examples presented in Chapter VI, there has been a move away from the concerns over technical considerations of perspective choice (isometric or focused), map viewing (viewing azimuth, elevation angle, vertical exaggeration), and map compilation to an emphasis on the clarity of the map product and the map's function as an information transfer mechanism. The increased use of 3-D maps for decision making roles in the resource planning and urban design fields are prime examples. As well, methods of 3-D presentation that were previously ignored because of technical considerations are now being used and evaluated. The maps presented in Chapter VI are examples.

The integration of computer graphics technology with cartography has also had some impact on changing the role of the map product. Due to the relative ease in creating maps, defining viewing methods, and the inherent *virtual* nature of the map product, the map has become increasingly used as a temporary or intermediary step in a geographic analytical process. The Bond Street data set provides a fine example. Only as maps are created and interpreted can the data analysis step be refined resulting in hypotheses about the data that are best displayed with another map product. The iterative process of *visual analysis* is paramount here.

The second aim of the research strictly reflects the cartographic viewpoint. With respect to the recent advancements in computer graphics technology, it was the aim to implement and evaluate 3-D cartographic representations as alternative methods for the management, display, and analysis of urban spatial data. Paramount to this idea is the notion that 3-D representations are meant to supplement the existing library of traditional 2-D methods that are used. Three dimensional maps may be used to augment existing displays of data sets that represent quantitative characteristics within a urban geographic area. The application of 3-D methods of display to quantitative data has not been addressed in this study.

The examples presented in Chapter VI clearly indicate the applicability of using 3-D representations for displaying and measuring urban spatial data. The emphasis has been on interpreting and visually analyzing the map product. Without the limitations of static displays and view blockage the spatial and temporal patterns in the UMIS 3-D maps are immediately evident. Limitations on the visual analysis of the 3-D map products are dependent on the data manipulation process and the resultant method chosen for displaying the results. The inherent advantage of the UMIS displays is the ability to integrate data from a variety of time periods in one display. The ability of the user to define the viewing selection criteria is also very important. This allows the user to only display the data that is immediately pertinent. Depending on the pattern that is evident data can be added based on a new hypothesis.

The success of the 3-D map products for presenting spatial and temporal patterns can only be evaluated in terms of the scope of the research aims. This research has only applied a small piece of urban spatial data to the 3-D world. A more complete evaluation on the use of 3-D cartographic representations for presenting urban spatial data can only be made if other types of urban data are incorporated. Example data types include land ownership data, tax parcel information, the location and characteristics of utilities, land use zoning areas, and elevation data.

While the use of the 3-D cartographic image has been successfully implemented and utilized within this case study it is important to note the map product does not stand alone. The application that was undertaken in Chapter VI clearly highlighted the need for use of the 3-D images with statistical information that was determined during the data subset selection stage and graphics processing stage. Patterns that became evident during the visual analysis process were enforced with statistical results that were created during data processing. The use of both products were quite complimentary.

The third aim of this study is from a strict geographic viewpoint. It was the aim of this research to effectively display and investigate the process of urban retail change for a high-fashion shopping street over time. The broad scope of urban retail change necessitated the definition of specific areas of interest by the urban specialist. Three initial areas of inquiry were identified. These are in no way intended as comprehensive measures of urban retail change, rather they focus on distinct retail processes of interest. They are identifying retail changes over time for selected addresses; identifying the average turnover of retail functions; and measuring the persistence of firms based on selected persistence criteria. The three graphics processing programs within UMIS reflect these retail processes.

Chapter VI presents one example for each process. Each specific example was designed by the urban specialist. Patterns of spatial and temporal dimensions are clearly noticeable and identified. Limitations identified in the review of these graphics products are presented in the next section of this chapter. Retail change within the context of the particular areas of interest is effectively displayed and measured. More detailed investigation into the specific patterns that became evident in the examples is left to the urban specialist. This is consistent with the design of the application software. The basis of the software design is an iterative process of visual analysis which is utilized most effectively by the application user. Suggestions and requests for enhanced capabilities in the quest for analyzing retail change more effectively are honoured in a consistent manner within UMIS. Throughout the development of this case study several software enhancements have been [illegible] allow UMIS increased capabilities within the context of analyzing retail data. All enhancements have been generic enough to allow for the application of other data sets in the future. This also is consistent with the design objectives of UMIS.

The last objective of this research is to provide and evaluate a practical application of the Intergraph interactive computer graphics system for computer-assisted mapping. The nature of geographic data management extends far beyond the idea of computer-assisted mapping. The development of UMIS has stepped into these new areas of application. For example, a variety of data manipulation and analysis algorithms have been implemented prior to the computer-assisted mapping step of the process. These data algorithms are based on existing approaches for data handling as well as some innovative ideas such as persistence that have been proposed by the urban specialist. This has increased the scope of the exercise beyond a strict computer-assisted mapping application.

However, within the context of computer-assisted mapping this research has presented an extensive practical application of the Intergraph system. The use of a distinctly slanted research theme and the 3-D approach has provided an application that previously had not been attempted. The implications of justifying an Intergraph system purchase including the financial considerations involved have traditionally necessitated its use for purely production oriented applications. This case study has clearly identified the effectiveness of the Intergraph system as a research tool for thematic applications in geography.

In particular, the use of 3-D techniques for this research theme is unique. Most 3-D applications utilizing computer graphics technology are done within the architectual or engineering discipline. Only recent advancements in the area of surface modelling have shown the application of 3-D representations to geography. Very little software exists today that is oriented towards urban infrastructure study utilizing any 3-D display capability. This application of a computer graphics system has incorporated the recent conceptual changes within 3-D cartographic research, ie. move away from purely visual considerations to emphasize the process of information display, as well as provided a framework with which other studies can be designed and evaluated.

7.3 Problems and Limitations

The problems and limitations encountered during the study fall into two main categories. These are data considerations and technical considerations. Each is discussed in order.

7.3.1 Data Considerations

Perhaps the dominant problem revealed during this research involved the dimensionality of the data. In particular this included the data classification stage. The urban specialists found it very difficult to incorporate the temporal change of retail environments. Changing definitions and methods of description for retail functions complicated the natural process of changing functions. Not only did some functions change over time, but the method to describe a specific activity also changed. This was further complicated by the eradication of some functions and the birth of new ones.

The dynamic nature of retail change was difficult to summarize in one classification scheme. The question arises how do we effectively compare qualitative data from different time periods. From the examples that were undertaken it became quite clear that much specialized knowledge is required to effectively eliminate the errors of assumption and maintain the reliability of the data. The *errors of assumption* are those errors in classification that are caused by assuming particular functions are similar to another without substantial field study to confirm these. The important point here is that a *data confidence* level is maintained. This idea is related to the notion of data accuracy and information loss. The classification process should attempt to typify the data set while minimizing the amount of information lost. A consistency within the classification scheme was maintained due to the urban specialists excellent background knowledge of the data set. The substantial amount of secondary data sources available for reference as well as the continued field surveys undertaken by the urban specialist helped to confirm the reliability of the data set. Nonetheless, the examples presented in Chapter VI as well as other test examples identified several miscodings and inaccuracies in the data. A review of various levels within the classification scheme is currently underway by the urban specialist.

Another problem encountered with the classification of the data set involved the selection of ground floor uses. A traditional problem in functional classification is the determination of ground floor uses. Generally, retail activities are located on the first floor of a building. This is commonly the case today on retailing streets. However, the primary data source, the Post Office London Street Directory, did not distinguish ground floor from upper floor uses. In fact often the same address was given. This was complicated by the inconsistency included in the capturing and reporting of the data for the time. The transfer of the data set to the digital files identified a variety of circumstances where establishments were listed at a specific address for a year and did not reappear for several time periods, sometimes 20 to 50 years. It was here the urban specialist used the secondary data sources to determine or hypothesize on the exact location of a particular establishment. Again it was only through examples such as are presented in Chapter VI that these miscoded upper floor uses are weeded out and eliminated from the data set. The cleaning of the data set is an ongoing process that occurs in spite of the time and care taken to validate and classify the data originally. The value of this type of geographic data processing is that it builds a comprehensive knowledge base about the data set by the user. It is during this that the user begins to understand the processes that have acted on the data and a more complete understanding of what other data supplements are required is established.

7.3.2 Technical Considerations

A variety of technical limitations became evident during the research process. Most of these are directly related to the tools that were used. A brief review of each is befitting.

The use of flat sequential ASCII files was appropriate as a data storage structure considering the size and content of the Bond Street data set. As identified in Chapter VI processing performance for the three examples was excellent. Any performance limitations, ie. the substantially longer time required for the DUR-FUNCTION runs, was due specifically to the nature of the software logic. The software is fairly clean and optimized for the file structures that are in place. Processing problems that were encountered during testing of the software often necessitated rewriting of several subroutines to optimize the performance and function of a program. It is expected however, that enhanced analytical and manipulative capabilities would require the use of a different data format for the attribute files. The use of an indexed file structure, ie. a relational data base product, would provide greatly increased data manipulation capabilities specifically where quick data retrieval was required.

Further to this discussion of data storage techniques a review of IGDS is appropriate. The Interactive Graphics Design Software (IGDS) supplied an excellent base for graphics display. The characteristics of screen resolution and manipulative capabilities combine to make it one of the best interactive computer graphics systems available. However, the capability for linking attribute data to the graphics product, while existing, is somewhat cumbersome and requires a good understanding and significant knowledge of the Data Management and Retrieval Software (DMRS) package. As previously mentioned in Chapter IV, the overheads of disk storage, processing requirements, and substantial software training, would not yield significant benefits that were directly applicable to the objectives of the research. Furthermore, the non-relational data base structure available with DMRS would not be conducive to the query type processing that would be required with this type of data set.

Another minor limitation within IGDS involved the use of 3-D cells. Cells are the IGDS element that is used to represent point symbols in a graphics design. The cell that was used in the examples presented appeared as a hollow cube. All cells must be created prior to graphics placement. The ability to create user defined point symbols is clearly a strong point of the IGDS software. However, the limitation is that 3-D cells cannot be placed with varying graphic parameters. In other words, once a cell is created all symbology for that cell is static with the exception of level. Since colour is a dominant visual variable employed in the 3-D representations several cells had to be created for the placement of one kind of point symbol. For example, to properly use the *cube* symbol at least eight cells had to be created and stored in the UMIS cell library. Each was created with exactly the same parameters except colour. The advantage of having 255 colours available to the user is eliminated by the practical considerations of having to have one cell for each colour for a particular symbol.

This limitation has implications beyond the mere creation of several cells however. The entire graphics processing software was designed around the need for multiple program runs to create one map product. Ignoring the obvious problem of increased processing time for obtaining duplicate information from the user this program design logic appeared more complicated to the application user than was really necessary. The introduction of any level of confusion to an analytical process as such reduces the usefullness and quality of the software program. The need for handling this cell limitation, while not a major problem, did contradict the design objectives of the software.

Another minor limitation was involved with respect to the dynamic viewing process. A distinct limitation exists as to amount of graphic elements that can de downloaded into the Terminal Data Set of the workstation and viewed dynamically. Some limitations existed not only in the size of the area that could be downloaded but the speed at which dynamic operations were performed. This limitation was quite evident in the examples as presented in Chapter VI. Since the visual analysis process is highly dependent on the ability to easily rotate and zoom in and out of the 3-D window this limitation is important to note. A potential problem was overcome by the capability to define a view rotation by X, Y, and Z angles relative to a view axes. This alternative method presented no problem in obtaining the perspective views that were necessary to visually analyze the map products. However, if a case study required a large data subset, ie. AVG-LENGTH for the whole street, obtaining the perspective views to properly analyze the data distribution patterns would become tedious and ultimately may restrict effective interaction with the map product. This is strictly a technical limitation and it is expected that it will be eliminated in future releases of the IGDS software.

The final technical limitation that presented itself involved obtaining views with hidden lines removed. Since movement within the 3-D file is virtually unlimited no hidden line removal can be performed interactively. Furthermore, none was required for the visual analysis of the map products. View blockage is not a concern when viewing the map product in this manner. Nevertheless, a specific software package was required to create clean hidden line views for hardcopy output. The Intergraph Hidden Line Removal software package (HLINE) was used to create static views with the hidden lines removed. No view manipulation was possible after hidden lines had been eliminated. This software design operates opposite to most 3-D graphics software that creates hidden line views on the fly after the user has alphanumerically defined a viewing azimuth, elevation angle, and vertical exaggeration. This method does not provide the ability for dynamic viewing however.

7.4 Recommendations for Future Study

Recommendations for future study includes a variety of approaches to this research. Suggestions are presented based on the rapidly developing technology of the computer graphics industry and the trends occurring in geographic data management. Considerations of the specific case study are also presented.

7.4.1 Technical Enhancements

The use of computer technology in any discipline must take into account the rapidly changing nature of the computer field. The application of computers to the cartography and geographic data management fields have spurred development that is unprecedented in either discipline. Particularly with the development of *geographic information system* approaches has the extent of tasks available to the user been vastly increased. The integration of multi-disciplinary techniques has been a major trend in geographic analysis. Accordingly, any research that attempts to investigate methods for geographic analysis and cartographic display must be aware of these new technologies and techniques that are developing.

The development of GIS technology since the initiation of this thesis research has been substantial. This thesis has attempted to incorporate the important concepts of GIS hoping that the developing technology would not make the research obsolete. Nonetheless, the integration of current GIS methodologies in the future would provide capabilities and approaches that were not utilized in this research. Perhaps the most important of these is the capability to incorporate a variety of other *data layers* into the statistical and graphics representation of the data. This would require the use of a data base management system to properly maintain and output data. Current relational data base approaches are exceptionally good for maintaining and adding data to existing data sets. The added capability to quickly query and create new information based on modelling formula is an inherent advantage to integrating this kind of technology.

Another trend in the data management arena is the move towards micro-computer based systems. Several micro-computer based 3-D mapping programs are available today. However, most of these are concerned with the display of continuous surface information. Very few can be utilized with thematic cartographic applications, particularly those that require traditional cartographic symbology, ie. proportional symbols. The ability to represent irregular point data with the 3-D medium is lacking in this regard.

The development of micro-computer GIS is the dominant trend in mapping related software applications. The current research is constrained by the use of an expensive mini-computer based system. The move to *personal computer* technology not only increases the flexibility of the software but it also greatly reduces the cost of obtaining, maintaining, and developing a data processing system. The user would have the advantages of a standalone workstation for their own personal use. The implications of CPU time are no longer a major concern. A move to micro-computer technology would require some modifications to the existing software as well as some changes in the conceptual design of future programs. However, the traditional limitations of CPU power and storage space are quickly being eliminated with the technological developments in the field. In fact the case study as presented in this thesis would have no problems with respect to disk storage space or processing power requirements given the technology of the current day.

Another spatially related technological development that may be valid for future research in the urban field is that of remotely sensed imagery. Traditionally, resolution limitations of remotely captured data have inhibited its use to larger resource based applications. However, with the influx of satellites that provide data resolution in the ten metre range, information may be extracted to adequately identify land related patterns. The notion of functional classification within urban areas is an immediate consideration. The use of this kind of approach is bounded by temporal constraints. It simply would not be useful for any studies that require temporal data in any great amounts. In any respect the use of remotely sensed imagery, satellite or not, requires consideration in future urban research.

7.4.2 UMIS Modifications

A variety of modifications could be made to the UMIS software with regard to software design and functional capabilities. As mentioned in the previous section the most obvious is the integration of a full relational data base capability. This would allow the easy inclusion of other related data layers into the data base. Examples of other data sources that may be valid in future processing include population information, average income data, tax parcel data, land ownership information, land use planning data, elevation data, and land value information. These other data sources would ultimately be described graphically in a linear or polygonal nature. This would require the use of a GIS approach for managing the different types of spatial data. A relational data base approach would also allow the analytical and modelling capabilities that would be required to order and manipulate the data sets into understandible representations. The use of 3-D images is still seen as a major display mechanism for the presentation of temporal patterns.

The other foreseen enhancements to the UMIS software are more specific. An initial improvement would be to redesign several of the programs to eliminate the physical creation of data files with matched attributes and positional coordinates. Coordinate data that was read from the positional data file could be matched virtually with the attributes and the graphic elements placed immediately. This would require quicker retrieval to both data files. A different data structure for both data files as discussed in the previous section is a necessity. This conceptual change would also result in less file storage being required and ultimately quicker graphics processing. The use of data subsets for the attribute data is still envisioned.

Another enhancement that is embodied in the move towards GIS technology is the establishment of increased analytical capabilities. This would include the incorporation of standard statistical analysis techniques as well as several approaches that are specific to urban geography. Techniques such as nearest neighbour analysis, retail persistence measuring, and central business district (CBD) indexes are classic examples.

The final obvious modification involves the creation of new graphics representations. The increasing technology of the computer graphics age has afforded the use of the 3-D surface in ways that previously were unimagineable. Further research should continue to investigate the techniques that exist for the representation of data using the third dimension. The creation of continuous surfaces and temporal profiles are an area of promise.

7.4.3 Case Study Considerations

Some suggestions for future study with respect to the specific case study are appropriate to conclude this section. The obvious enhancement mentioned in the previous sections is the addition of other valid data layers. Within the scope of the existing interests of the urban specialist a need has been shown to densify the interval of the five year data set. Densifying the resolution of the data to a two year interval would provide a substantial basis for justifying the results of the examples. Without doubt the increased data content would provide many more clues as to the nature of retail change on Bond Street as well as eliminate many of the inacurracies that are current and assumed with the existing data. The advantages of an increased reliability with the data combined with the substantial knowledge of the study area by the urban specialist would result in an information system which could yield some very innovative and original results.

Perhaps the primary modification would involve a complete reevaluation of the classification scheme that was utilized. This process is currently underway by the urban specialist. The results of any analysis are directly dependent on the quality of the classification scheme. The examples presented in this thesis as well as others that have been undertaken have necessitated a reexamination of the definition criteria for the classification scheme. Close scrutiny of the classification criteria may result in the definition of several pertinent classification methods for an urban retail data set. The application of several relevant classification schemes would be especially easy to undertake if a relational data base structure was adopted.

7.5 Summary

The application of the Bond Street retail data set has clearly shown that there is a role to be played by 3-D maps in the management and analysis of urban spatial data. Three dimensional mapping is a viable alternative when dealing with urban thematic data. The use of such map products should not be considered a replacement for existing methods of thematic display in cartography. Three dimensional maps should supplement traditional map products to present data characteristics that are not easily identified in a two dimensional medium. The area of temporal data sets is an obvious application. Notwithstanding, the use of 3-D maps will continue to increase with the developing technology of computer graphics. Much thought should be given to the purpose of the map product and the proper application of this technique.

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Appendix 1. Glossary of Computer Processing Terminology

access environment

A general term used to describe the command procedure that allows users access to the program selection menus. An access environment supplies a variety of menus to the user to allow him/her to perform selective tasks.

account

A particular identifiable activity that is understood and logged by the operating system. An account refers to a valid log on identification activity. Accounts are established by the system manager and the operating system can only be accessed via these defined accounts.

address migration

The process of addresses moving and changing on a street over time. Migration includes the physical movement of an address, as well as the agglomeration of one address with another.

address space

The set of all possible addresses available to a process. Virtual address space refers to the set all possible virtual addresses. Physical address space refers to the set of all possible physical addresses used to refer to locations in memory and device registers.

alphanumeric keyboard

The hardware device that allows the user to enter alphanumeric textual commands into the system. The keyboard appears basically as a keyboard does on a typewriter.

architecture

Refers to the structural design of the computer.

auxilliary storage

Refers to additional or supplemental storage devices other than memory. Disk drive devices are considered primary auxilliary storage.

block

A quantity of disk space or data consisting of 256 words (512 bytes).

byte

A byte is 8 contiguous bits starting on any addressable boundary. A byte can be used to store 1 ASCII character.

C

A mathematical computing language that has recently become popular in the digital mapping field. The C language affords many more capabilities than FORTRAN and is being used increasingly in digital mapping applications.

cell

A group of graphic elements that form a symb [illegible] e graphic elements that make up a cell are stored together as a complex [illegible]ement. Accordingly, cells are manipulated as one symbol.

cell library (file)

The basic file entity used by Intergraph's graphic software for the storage of permanent graphic symbols. Ce[illegible] libraries are files used [illegible] e storage and retrieval of commonly used, user defined graphic symbols. Ce[illegible]oraries must be a group of contiguous blocks to be used.

cell origin

The point around which a cell is always placed.

central processing unit (CPU)

The central processor tches instructions from memory, decodes them, and performs the arithmetic, logical, and control operations called for by the instruction.

command button (C)

The button on the cursor that allows the user to select and activate des rec commands from the menu.

command driven

An approach used in application software that utilizes a command prompt for obtaining user input. This method is opposite to a panel driven approach.

command interpreter

The section of the system software that parses out and interprets input commands.

command level programming

A general term that refers to the creation of command procedures using DCL.

command menu

A physical hardcopy paper graphic that supports all of the requests for the creation and manipulation of graphic elements in a design file.

command procedure

A file containing DCL commands and data that the command interpreter can accept and process in lieu of the user typing the commands individually on a terminal.

compiler

A language processor that translates a source program containing high level language statements (ie. FORTRAN) into an object module.

contiguous

A group of storage blocks that are located one after another on disk. Design files and cell files must be contiguous to be utilized in the IGDS software and it's interfaces.

cursor

A hand held device that moves across that command menu and digitizing table allowing the user to reference commands on that menu as well as data points within the design file.

design file

The basic graphic file entity used by Intergraph's graphic display software. A design file is a quantity of graphic information located on disk in a group of contiguous blocks (512 bytes). Design files must be larger than 5 blocks in length and are scanned by the system hardware for the purpose of bringing the file to the terminal screen. Design files are open ended in structure and are only limited in size by the hardware configuration.

digitize

The process of coding graphic information (drawings) from paper into the computer system.

digitizing table

The physical sensitized worksurface of a graphics workstation that affords the ability to digitize hardcopy graphics into the computer system.

element colour (CO=)

A number between 0 and 255 representing the colour of a specific graphic element. Actual hues and shades are created in a colour table and assigned numeric codes. Elements defined a specific colour code will display the colour defined by that number. Therefore, actual element colours are dependant on the colour table attached to the file.

ergonomic

Refers to the scientific study of the relationship between human beings and their working environment, in this case computer hardware, with a view to increasing efficiency.

executable image

An image that is capable of being run in the context of a process. The result of a linking process.

Files 11 Structure

The name of the online disk storage (file) structure used by the VAX/VMS operating system. This structure defines for the user the method of naming and storing files on the system. This also includes defining the directory structure utilized by VAX/VMS.

floating menu

A tablet containing a computer command menu that is flexible in its movement across the digitizing table. The floating menu is attached to the digitizing table by a physical cable.

font (FT=)

Font refers to a particular type of lettering assigned to a text element. The numbers 0 to 84 are used to identify different text font types.

GRAPHICS

The primary mode of operation within the IGDS environment. This mode allows the user interactive access to graphic design files.

graphics workstation

A physical item of hardware that allows the user access to other hardware devices and software. In the Intergraph configuration, a graphics workstation allows the user access to the GRAPHICS mode of operation via several physical hardware devices (digitizing table, command menu, alphanumeric keyboard, cursor).

hardware

The mechanical, magnetic, electrical, and electronic devices or components of a computer system.

HELP

An online help facility provided by Intergraph in the IGDS environment. This help facility supplies documentation required for the operation of the IGDS subsystems.

I/O

A general term that refers to computer input and output.

lexical function

A special DCL function (command) that returns information about character strings and attributes of the current process. Lexical functions are commonly used in command procedures to obtain specific information about the user's process and/or procedure variables.

level (LV=)

The active overlay on which graphic elements are defined. IGDS design files permit 63 identically sized levels for the placement and subsequent distinction of elements. Currently the major distinguishing parameter in IGDS design files.

line code (LC=)

A number between 0 and 7 that identifies the style of line for a graphic element. Line codes available include solid, dotted, short dash, medium dash, long dash, dash-dot, dash-dot-dot, and long dash-short dash.

line weight (WT=)

A number between 0 and 31 that represents the thickness of the graphic element.

linker

A program, existing as a system utility, that reads one or more object files created by a language compiler and produces an executable image file.

log on

To perform a sequence of actions at a terminal that establishes a user's communication with the operating system and sets up default characteristics for the user's terminal session. Sometimes referred to as log in.

machine code

A sequence of binary machine instructions in a form executable by the computer.

main memory

See physical memory.

memory management

A general term to describe the system functions that include the hardware's page mapping and protection, and the operating system's image activator and pager.

modal class

The numerical class (mode) that occurs most frequently in a given data set.

multiprogramming

The concurrent memory residency of more than one program.

object module

The binary output file of a language compiler which is used as input to the linker.

OF=

This key-in blanks a specific level (or group of levels) from display on the graphics terminal. Levels can be turned off at will.

ON=

This key-in brings a specific level (or group of levels) to display on the graphic terminal. Levels can be turned on at will.

on-line

The act of being logged on to an operating system interactively.

page

A set of 512 contiguous byte locations beginning at an even 512-byte boundary used as the unit of memory mapping and protection.

panel driven

An approach in application software that utilizes a friendly menu system for obtaining user input.

physical address

The address used by hardware to identify a location in (1) physical memory, or (2) on directly-addressable secondary storage devices such as disk.

physical memory

The memory that is used to store (1) instructions that the processor can directly fetch and execute, and (2) any other data that a processor is instructed to manipulate. Also called main memory.

pixel

An abbreviation for picture element. A pixel is a square portion of the graphic image that is representative of the finest resolution displayed in that image.

process

The basic entity scheduled by the system software that provides the context in which an image executes. A process consists of an address space and both hardware and software context.

program

A logical sequence of instructions written in a computer language that tells the computer how to solve a specific problem.

program overlays

The different task overlays of a specific program. Program overlays are required on computers that have finite memory size limits. For example, the PDP 11 series of mini-computers had a size limit of 28K words for any routine. Program overlays are a major limitation for graphic applications in an non-virtual computer environment.

readonly

Implies that access to a file or device by a process program is limited to reading data only. No writing to that file or device is allowed.

run

To activate or execute a procedure or image.

snapping

A task that allows the user to locate exact elements in a design file. Snapping is achieved throught the tentative point button on the cursor.

software

The programmed logic that enables the hardware to execute tasks.

swapping

The method for sharing memory resources among several processes by writing pages to secondary storage (swap out) and reading other pages into memory (swap in).

terminal data set (TDS)

High performance terminals based on the MC68000 micro-processor contain a significant amount of memory capacity within their own hardware and also have a programmable display device called the Display Processor. This provides the ability to load a portion of the drawing data into the workstation for rapid use, thus reducing dependence on the host processor. The drawing data that is loaded into the terminal is called the Terminal Data Set (TDS). This feature greatly increases the speed of operations such as pan, zoom, and dynamic rotation.

text height (TH=)

This refers to a working unit definition of the height (length) of a text element.

text width (TW=)

This refers to a working unit definition of the width of a text element.

UNIBUS

An asynchronous communicatons path connecting the UNIBUS interface (adaptor) to a variety of peripheral devices.

UNIBUS interface (adaptor)

The interface between the UNIBUS and the VAX 11 system.

user command

A user command is a series of graphic instructions inserted into a text file. Upon invoking a user command all instructions are processed by the system in an orderly fashion.

user command language

An Intergraph defined language format that must be used in creating user commands.

user friendly

Implies a design (hardware or software) that is friendly to use. Commonly refers to the removal of confusing or intimidating computer terminology or processes from a user action.

UTILITIES

The secondary mode of operation within the IGDS environment. This mode allows the user to perform a variety of file manipulation utility functions.

variation ratio

A commonly used index for nominally scaled data (qualitative) that indicates the measure of variation in a given data set. Usually is a value between 0 and 1. The nearer the value is to 0 the better the modal class is as a summarizing statement for the data set.

virtual address

A 32-bit integer identifying a byte location in virtual address space. The memory management hardware translates a virtual address to a physical address.

virtual address space

The set of all possible virtual addresses that an image executing (in the context of a process) can use to identify the location of an instruction or data item. The virtual adddress space seen by a programmer is a linear array of 4,294,967,296 (2**32) byte addresses.

working units

The factors representing a specific unit of measurement that define the UOR's of a design file to a particular level of accuracy. The working unit definition allows the user to compare the design area to a real world coordinate system.

Appendix 2. Modified Standard Industrial Classification Scheme

	000000	Vacant, non-economic, or missing
AGRICULTURE	010000	DIVISION A :
	020000	
	030000	DIVISION B :
LOGGING	040000	DIVISION C :
FORESTRY	050000	
MINING	060000	DIVISION D :
	070000	
	080000	
	090000	
MANUFACTURING	100000	
LEATHER & ALLIED	170000	
LEATHER	171000	
	171900	razor strap mkr
TEXTILE PRODUCTS	R190000	
OTHER TEXTILES	199900	
	199910	bookbinder cloth mfr
	199920	candle wick tufiers
INDUSTRIES	250000	
WOOD BOX,PALLET	256000	
	256100	presentation boxes
OTHER WOOD IND	259000	
	259900	tray mkr
	623811	upholder
	623812	upholst
	623813	upholder cab mkr
	623814	upholst cab mkr
	623815	upholst decorators
PAPER & ALLIED	270000	
CONVERTED PAPER	279000	
	279200	stationer mfr
	281200	printers
	282110	bookbinder
	283100	publ
	283200	publ church
	283300	publ fine art
	283400	publ book & print
	284100	publ newspaper
	305900	pat wire cartridgemfr
	329110	carriage builder
	329121	coach builders
	329122	coach & harness mkr
	337900	motor mfr
	351220	tesselatedpavementmfr
	356300	vacuum jars
	379900	shoes boots black mfr
	391210	math instr maker
	391220	measuring instru mkrs
	391400	photo apparatus mfr
	391510	surgical instrumt mkr
	391520	surgicalins&bandgemkr
	392100	jwlr mfr

393210	military miniaturemkr
399410	record mfr
399420	record producers
399910	invalid furn mkr
400110	builder
400120	carpenter
400130	painter plumb glaser
623921	appraiser & cab mkr
623911	cabinet mkr
623931	joiner manfu
623931	joiners mfr
623941	carver & gilder
400170	artists stained
458910	livery stables
458920	jobmaster
458930	carriers
458940	vet surgeon
482100	telegraph off
484100	post office
523311	hair shampoo mkr
523312	hairdressing prep.
523320	perfumer who
523321	perfume distributors
523322	perfumer agts
523330	eau de cologne import
531010	couture who
531020	fashion agent consult
531030	fashions mfr cloth
531041	knitted goods mfr
531042	knitted goods who
531043	knitted goods wolnmfr
531050	fashions rainwear mfr
531061	belt mkr
531062	belt mkr wom
531063	elastic belt makers
531070	sportswear mfr
531111	blouse mkr who
531112	blouse mfr
531121	costume mkr who
531122	costume mkr whs
531130	dress agency
531140	fashions who wom
531150	outerwear mfr wom
531160	sportswear mfr wom
531210	fashions men who
531220	fashions men agents
531230	shirt mfr
531241	tie mkr
531242	tie mfr
531400	furrier who
531521	milliner mfr
531522	milliner suppliers
531523	milliner who
531620	handbag mfr
531810	shoes footwear agents
531820	shoes boots mkr who

	532200	thread mfr
	532300	textile mfr
	532400	woollen mfg
	532500	woln dlr knitwear agt
	532600	rayons
	532700	silk mfr
	535200	soap &toilet prep mfr
	541100	elect goods merch who
	542100	cigar dlr who
	543210	sheepskin rug mfr
	543220	sheepskin who
	551100	motor car agents
	561900	stainless steel goods
	563100	hardwood merchant
	579110	office furnishers
	579120	office furnishertypwr
	594100	fancy goods mfr
	594211	bicycle mkrs
	594212	bicycle saddle
	594221	rubber sports goods
	594222	sports goods mfr
	594223	sports goods who
	596110	jwlr brokers
	596120	jwlr who
	596130	jwlr who secondhand
	599300	gutta percha whs
	599911	leathergoodmetlframer
	599912	leather mfr
	599913	leather reptile skins
	599920	revalenta arabica imp
	599930	brush mkr toilet
RETAIL TRADE	600000	DIVISION J
	610000	
	620000	
	630000	
	640000	
	650000	
	660000	
	670000	
	680000	
	690000	
FOOD,BEV,DRUG	60	> 60xxxx
FOOD STORES	601	> 601xxx
VIANDE	601200	
	601211	butcher
	601211	butcher vension dlr
	601212	poulterer
	601213	fishmongers
DAIRY	601220	
	601221	butterman
	601222	cheesemongers
	601223	chessemonger&butterme
	601224	dairy
PRODUCE	601230	

	601230	produce merch
FRUIT	601240	
	601241	fruiterers
	601242	fruiterers & florist
BAKER	601250	
	601250	baker
CONFECTIN	601260	
	601261	chocolatiers
	601262	confectioners
	601263	confectionfrench&choc
	601264	confection pastrycook
	601265	candies and jellies
GROCERS	601270	
	601271	grocers
	601272	provision merch
	601273	groc & italian whs
	601274	italian warehouse
	601275	foreign oil warehouse
	601275	foreign warehouse
	601275	oil & italian whs
	601276	oilman
	601276	oilman fishsauce whs
TEA&COFFE	601280	
	601281	tea dlr
	601282	tea & coffee dlr
	601282	tea & coffee drl
	601283	tea & italian warehou
	601284	teamen & grocers
MSC FOOD	601290	
	601291	ice merch
	601292	yeast powder mfrs
	601293	mineral water mfr
WINE & LIQUOR	602000	
LIQUOR	602100	
BEER	602200	
WINE	6023	> 6023xx
	602300	wine merch
	602400	cider merch
	602510	wine & spirit merch
	602520	wine & brandy merch
	602530	wine & spirit vaults
	602600	wine & cigar merch
	602700	wine spirit cigar mer
	602800	wine&min wtr importer
PRESCRIPTIONS & PATENTED MED.	603	> 603xxx
CHEMIST	6031	> 6031xx
	603100	chemists
COSMETICS	6033	> 6033xx
	603310	cosmetic retlr
	603320	cosmetic mfr

PERFUMES	6034	> 6034xx
	603410	perfumer
	603410	perfumer retlr
	603410	perfumer retlr (rem)
	603421	perfumer mfr
	603422	perfumer mkr
	603430	perfumer soapmkrfancy
	603440	perfumer & comb mkr
TOILET PR	6035	> 6035xx
	603510	toilet prep
	603521	toilet requisites
	603522	toilet requisites mfr
SOAPS	6036	> 6036xx
	603611	soap mfr
	603611	soap mfr milk
	603612	soap mkr
	603620	soap & candle maker
RAZORS	6037	> 6037xx
	603700	razor mkr
WAX	6038	> 6038xx
	603811	wax & tallow chandler
	603812	wax chandler
	603820	wax bleachers
BRUSH&COM	6039	> 6039xx
	603910	brush comb mkr
	603921	brush mfr
	603922	brush mkr
APPAREL & FABRIC	61	> 61xxxx
GENERAL APPAREL	610	610xxx
FASHION	6101	> 6101xx
	610110	fashions
	610120	couture
	610130	fashions men wom
	610140	fashions men wom chil
	610150	fashions trendy
	610160	fashions discount
	610170	fashions rainwear
	610180	indiarubber waterproo
	610191	depot de modes
	610192	modes et robes
	610193	model mkr paris
	610210	outfitter
	610310	knitted goods merch
	610320	knitted good wolmerch
	610340	homespun merch
	610350	woollen merch
	610410	sportswear dlr
	610510	tailor habit mkr
	611110	fashions wom

6112101	outfitter wom
6112102	outfitter wom retlr
611311	tailor wom
611312	tailor wom crt
611322	costume mfr
611321	costume mkr
6113212	costume mkr crt
611410	blouse retlr
611420	blouse mkr
611511	dressmkr
611511	dressmkr veneet repr
611512	dressmkr crt
611530	dressmkr furrier crt
611540	dressmkr lingerie
611550	dressmkr mill fur crt
611560	fashions skirt mkr
611610	gown retlr
611620	gown mkr.
611630	gown mfr
611710	mantle mkr
611720	mantle designer
611731	india shawl whs
611732	shawl whs
611810	trousseaux
611910	corset mfr
611910	corset mkr
611921	lingerie
611922	lingerie mfr
612110	fashions men
612210	outfitter men
612220	outfitter colonial
612230	outfitter military
612311	tailor
612312	tailor art
612313	tailor men
6123212	tailor breechemkrridg
6123211	tailor breeches mkr
612322	tailor trouser mkr
612330	tailor military
612340	tailor hosier
612350	tailor outfitter
612361	tailor water proofer
612362	antigropelo mfr
612410	shirt mkr
612420	gloves shirtmkrs hose
612420	shirt mkr hose glover
612431	hosiers shirtmkr
612431	shirt mkr hosiers
612432	hosiers shirtmkr whs
612433	hosiers whs
612440	glovers shirtmkrs
612510	underwear retlr
612520	truss mkr
613111	childrens wear
613112	outfitter school
613120	juvenile whs

614100	furrier retlr
614101	furrier
614200	furrier mfr
615110	glover retlr
615120	glover crt
615132	glover mfr
615131	glover mkr
615211	hatters
615212	hatters men
615220	hatters mfr
615230	hatters glover
615310	milliner
615320	milliner retlr
615330	milliner crt
615340	hatters wom
615350	hatters ride fur dres
615360	milliner dressmkr
615370	milliner dressmkr crt
615380	milliner comb mkr
615410	hatters & e. india wh
615420	hatters & milliners
615510	hosiers
615520	hosiers glovers
615530	hosiers outfitter
615540	hosiers mfr
615550	hosiers wom
615560	hosiery whs shetland
615570	hosiers brace mkr
615610	hair wig mkr
615620	hair ornamental mfr
615630	peruke mkr
615640	peruke mkr & perfumer
615650	wig mkr & hair dress
616100	leather goods
616210	handbag retlr
616220	handbag mkr
616310	fan mfr
616411	umbrella mfr
616412	umbrella mkr
616413	umbrella whs
617100	linen retlr
617100	retlr
617200	linen mfr
617300	linen draper
617410	linen whs
617420	linen whs baby
617430	linen whs household
618110	shoes boots retlr
618121	shoes boots retlr wom
618122	shoes wom
618131	shoes boots retlr men
618132	shoes men
618141	shoes men wom
~~618142~~	shoes men wom fsn lea
618211	shoes boots mfr
618212	shoes boots mkr

618221	shoes boots mfr wom
618222	shoes boots mkr wom
618310	shoes boots mkrwaterp
618320	shoes foot comforts
619111	fabrics
619112	fabrics artistic
619120	fabrics dress
619130	couture fabrics
619140	textile merch
619151	mercer men
619152	mercer & woln draper
619160	drapers & hosiers
619212	embroiderers
619212	embroiderers muslin
619213	embroidery depot
619220	fancy work repository
619231	fancy fringe mfr
619232	fancy fringe mkr
619240	laceman gold
619310	lace dlr
619320	laceman
619330	lace whs
619340	lace mfr
619350	lace depot
619360	lace accessories
619410	silk mercers
619420	silk merch
619430	silk whs
619440	silk mercers &lacemen
619510	woollen merch
619520	woollen draper
619530	woollen whs
619551	scotch tweed mfrs
619552	scotch whs
619600	fabrics (linen)
619701	east india warehouse
619702	oriental whs
619810	button merch
619820	calico printers
621211	furn dlr
621212	furn importer
621221	furn mfr
621222	furn mfr artistic
621231	buhl mfr
621232	buhl &carved furn dlr
621240	marqueterie mkr
622101	electrical appliances
622102	electrical clocks
622200	gramophone dlr
622300	razor serv centre
622400	sewing machine dlr
623110	carpet retlr
623120	carpet mfr
623210	furnishing fabrics
623220	art decorative art
623250	accordian pleater

623260	window blind manuf
623311	china glass merch
623312	china porc
623313	china glass whs
623321	china glass mfr
623322	china mfr
623323	china porc mfr
623323	china porc mkr
623324	venetian glass manf
623411	chandelier mfr
623412	chandelier mfr&lustre
623413	lamp & lustre mfr
623414	lamp warehouse
623416	lamp glass&lustre mfr
623417	lamp mfr
623418	lamp mkr
623420	lamp mkr & oil merch
623430	elect lightfittingmfr
623441	elect light shade mkr
623442	lamp shade mkr
623500	house furnishers
623601	art pottery importers
623602	art pottery mfr
623603	art pottery terra cot
631110	motor car bodybuilder
631120	motor car dlrs
631130	motor car mkrs
631140	motor co
631150	motors (?)
623711	decorators
623712	art decorator
634200	motor accessories
641110	department stores
641120	department st oversea
641300	discount house
641420	variety store ??
641510	mail order office
651111	bookseller
651112	ant books
651113	bookseller publ
651114	bookseller & library
651115	bookseller stationer
651116	booksel station libr
651121	library
651122	library & opera agts
651131	stationer
651131	stationer crt
651132	stationer bookseller
651133	stationer heraldic
651134	stationerdresscasemkr
651135	printer stat newsagen
651140	glass paper agnt
651150	fountain pen dlr
652110	florist
652120	florist artificial
652310	seedsmen

652320	seedsmen & florists
653110	furnishing ironmonger
653311	lock mkrs
653120	ironmongers
653130	furn stove mfr
653140	ironfounders
653151	bronze dlr
653152	bronze mkr
653312	locks patent dlr
653320	locks pens desks
655111	musical instrumentdlr
655112	musical instrumentmkr
655113	musical instrumentmfr
655121	piano dlr
655122	piano mkr
655123	piano mfr
655124	piano organ dlr
655130	violin mkr
655210	music pub sel instmkr
655311	music
655312	music department
655313	music publ
655320	music seller
655330	music seller & publ
655340	music repository
655350	music circulating lib
655360	music whs
655500	gramophone record dlr
656111	jwlr retlr
656112	jwlr retlr ivory spec
656113	jwlr retlr leather
656113	jwlr retlrcostumeleat
656114	jwlr cultured pearls
656115	jwlr diamond set
656116	ivory turner
656121	jwlr goldsmith
656122	artists hair&goldsmit
656123	jwlr goldsmith gunmkr
656124	jwlr gold silversmith
656125	jwlr silversmith
656125	jwlr silversmith(rem)
656126	jwlr silversthdresbag
656131	jwlr imitation
656132	jwlr retlr imitation
656141	jwlr ant
656142	jwlr retlr ant
656143	ant silver
656150	amber specialists
656161	jwlr watch mkr
656162	jwlr watch mfr
656171	cutler
656172	cutler&dress case mkr
656173	cutlery mfr
656181	dressing bag mkr
656182	dressing bag mkr jwlr
656183	dressing case mfr

656184	dressing case mkr
656185	dressing&writcase mfr
656186	dressingcasepktbk mfr
656187	musical boxes
656191	engraver
656192	silver engraver
656193	engravers seal
656200	jwlr watch reprs
657100	photo dlr apparatus
658110	toy dlr
658120	toy mfr
658130	toy mkr
658140	toy whs
658150	toy whs&fancybrushmkr
658210	curio trading
658220	curiosity dlr
658230	fancy goods merch
658240	gift boutique
658250	heraldic shield mkr
658260	russian peasant indus
659111	ant dlr
659112	ant furn
659113	ant dlr
659113	art ant dlr
659210	optician
659220	optician inst mkr
659230	optician inst retlr
6593111	art dlr
6593112	art dlr expert
6593113	art dlr importer
6593114	art dlr res cln
6593115	artist & pictimporter
6593116	artist & art pict dlr
659312	art dlr printsel
659313	art importer
659314	art pict import & res
659315	art print dlr
659316	art print booksel
659317	art com agent
659318	art depot burmese
659321	art picture res
659322	art packers
659323	art expert
659324	artists colorman
659331	artist
659332	artist portrait
659333	artist min painter
659334	artist & picture res
659335	artist & photographer
659337	artist in wax
659341	art fine art assoc
659342	art society
659343	art society
659344	art society french
659345	artist min paintersoc
659410	camp equipage mkr

659420	portmanteau mkr
659430	trunk mkr
659440	trunk dress bag mkr
659450	travel goods dlr
659461	saddler
659462	military saddler
659470	bag maker
659600	dog dlr
659710	coin dlr
659721	stamp dlr
659722	stamp auctioneer
659911	auctioneer
6599112	commsn agt
659912	auctioneer
659913	auctioneer &estate ag
659921	cigar merch
659922	cigarette retlr
659923	tobacconist
659924	smokers requisites
659925	tobacco pipe mfr
659927	cigarette mfr
659930	gun mkr
659940	newsagents
659950	perambulatr mfr
702100	bank
771100	employment agency
771300	governesses agency
773100	accountants
774100	advertising
774910	artist commercial
774920	audio-visual consult
775200	motor engineers
777200	musical agent
777310	theatrical agent
777320	theatrical manager
841100	trade office govt
841120	political embassy
865210	surgeon
865220	surgeon dentist
865230	surgeon & bath proprt
865300	dentist
866900	accoucheuse
911101	hotel
911102	hotel private
911400	lodging house
921110	cafe
921120	restaurant
921130	tea rooms
921140	refreshment rooms
921300	cafe take out
921400	caterers
922100	pub
963910	ticket off [illegible]
963920	ticket off theatre
963930	concert agent
963940	ticket off theatrelib

966100	turf accountant
969100	billiard rooms
969900	shooting agency
971210	beautly specialists
971221	hair dres
971222	hair dres hat hosiers
971230	hair specialist
971240	hair restorer
971250	manicurist
971311	electrolysis
971312	electro therapy
972400	cloth repair
972400	cloth repair inv mend
972421	lace cleaner
972422	lace mender
972430	glove cleaners
972600	carpet restorers
972900	dyer
979100	shoes boots repairs
979911	massage
979912	masseuse
979920	elect baths
986100	club - private
986200	club-restaurant
986300	tea association
993111	photographer
993112	photostudio eleclight
993113	photo specialist
996110	airline
996120	travel agents
996130	tourist office govt
996140	rail booking rec off
996200	tour operators

Categorization of the classification scheme - ATTRIBUTE.COD

CAT-CLASS-I-START, Processing started at 23-JUL-1987 13:59:53

CAT-CLASS-I-SUMMARY, Processing Summary at 23-JUL-1987 14:02:23

Input Coded file = QSA1:[002021.UMIS]ATTRIBUTE.COD (19X,A6)
Output Summary file = QSA1:[002021.UMIS]ATTRIBUTE-CLASS.SUM.

Code range is from **0** to **996200**.

Number of different 1 digit codes ...: 11
Number of different 2 digit codes ...: 53
Number of different 3 digit codes ...: 108
Number of different 3 digit codes ...: 218
Number of different 5 digit codes ...: 458
Number of different 6 digit codes ...: 640

Number of different "0xxxxx" codes ....: 10
Number of different "1xxxxx" codes ....: 8
Number of different "2xxxxx" codes ....: 15
Number of different "3xxxxx" codes ....: 18
Number of different "4xxxxx" codes ....: 10
Number of different "5xxxxx" codes ....: 68
Number of different "6xxxxx" codes ....: 446
Number of different "7xxxxx" codes ....: 11
Number of different "8xxxxx" codes ....: 7
Number of different "9xxxxx" codes ....: 46

Number of BLANK codes found and ignored...: 58
Number of TOTAL codes read ....: 730

CLASS-I-FINISH, Processing Complete at 23-JUL-1987 14:02:24

Appendix 3. Bond Street Case Study Base Map