ISSUES IN THE ADOPTION OF GEOGRAPHIC INFORMATION SYSTEMS FOR SCHOOLS PLANNING IN NEWTON, MASSACHUSETTS

by
Paul B. Cote
B.A., Geography
Indiana University, 1984

Submitted to the Department of
Urban Studies and Planning in Partial Fulfillment of
the Requirements for the
Degree of
Master of City Planning

at the
Massachusetts Institute of Technology

May 1993

© Paul B. Cote 1993
The author hereby grants to MIT permission to reproduce and to distribute publicly copies of this thesis document in whole or in part.

Signature of Author: ____________________

Department of Urban Studies and Planning
May 18th 1993

Certified by ____________________

Lyna L. Wiggins
Associate Professor, Center For Urban Policy Research
Rutgers University
Thesis Supervisor

Accepted by ____________________

Chair, Master of City Planning Degree Committee

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
ISSUES IN THE ADOPTION OF GEOGRAPHIC INFORMATION SYSTEMS FOR SCHOOLS PLANNING IN NEWTON, MASSACHUSETTS

by

Paul B. Cote

Submitted to the department of Urban Studies and Planning on May 18th, 1993 in Partial Fulfillment of the requirements for the Degree of Master of City Planning

ABSTRACT

An eighteen-month cooperative research project was carried out between Newton Public Schools and the Planning Support Systems research cluster at the Massachusetts Institute of Technology to explore applications of desktop geographic information system software (GIS) for school planning, and to explore the issues surrounding the implementation of these applications. Newton, Massachusetts is a city of approximately 83,000 people, located in the Boston Metropolitan area. The school system serves approximately 11,000 students.

Newton is currently implementing a centralized municipal GIS. A major concern of the school administration is whether investment in school planning applications would be made obsolete when and if the schools become part of the central GIS. The research described in this thesis involved in-depth studies of the planning and administrative goals, procedures, as well as the information resources available within the schools department and other city departments.

It is concluded that desktop GIS applications would improve the efficiency and responsiveness of school planners. It is recommended that municipal departments such as Newton Schools begin to develop their capacity to manage and analyze electronic information resources in order to utilize desktop GIS. If well planned, the investments would enhance the overall effort to develop a coordinated municipal GIS.
ACKNOWLEDGEMENTS

The research for this thesis was supported in part by a grant from Laidlaw Transit, Inc. Kenneth Tempkin, the Coordinator of Transportation for the Newton Public Schools, deserves credit for providing the inspiration for this study plus the essential elements of a creative atmosphere in which to work and the flexibility and support for learning and exploring issues. The other regulars at the transportation office, Laura, Judy and Valerie supported this effort with their willingness to share information and contacts, their good cheer, and with great food.

My advisor, Professor Lyna Wiggins, provided very useful insights into the institutional issues of GIS acceptance, and very valuable assistance with the writing process. Both Professor Wiggins, and my reader, Professor Joseph Ferreira, Jr. contributed to this work by pushing me beyond the issues of one school department to conclusions concerning municipal GIS implementations in general.

Biographical Note:

The author attended Indiana University's Bloomington campus between 1979 and 1984. He received a Bachelor's Degree in Geography with a certificate in Urban Studies from I.U. in 1984.

After six years working in the commercial map publishing industry in central Texas, he was admitted to the Department of Urban Studies and Planning at the Massachusetts Institute of Technology. Participating in the Planning Support Systems Curriculum Focus, the author pursued coursework and research oriented toward discovering ways that information technology can improve the understanding of planners and the public of processes and the environment.
### TABLE OF CONTENTS

1. **INTRODUCTION**

1.1 Background ................................................................. 9
   1.1.1 Geographic Information in School Administration ............ 10
   1.1.2 Mainframe Computing Applications ................................ 10
   1.1.3 Geographic Information Systems .................................. 10

1.2 Alternatives ................................................................. 11
   1.2.1 Municipal GIS ........................................................ 11
   1.2.2 Consultant Packages ............................................... 11
   1.2.3 Generic Desktop GIS ............................................... 11
   1.2.4 Exploring the Alternatives ....................................... 12

1.3 Structure of the Thesis .................................................. 12
   1.3.1 Summary of GIS Functions ....................................... 12
   1.3.2 Literature Review ................................................ 12
   1.3.3 Applications of Desktop GIS for Newton Public Schools ..... 13
   1.3.4 Issues in Implementation and Maintenance .................... 13
   1.3.5 Conclusions ....................................................... 13

2. **FUNCTIONS OF DESKTOP GIS**

2.1 Geographic Information Systems ....................................... 15
   2.1.1 Spatial Objects .................................................. 15
   2.1.2 Attribute Data .................................................. 16
   2.1.3 Layers and Tables .............................................. 16

2.2 Desktop GIS Functions .................................................. 16
   2.2.1 Graphic Display of Spatial Objects ............................. 17
   2.2.2 Association of Spatial Objects with Attribute Database ..... 18
   2.2.3 Thematic Mapping .............................................. 18
   2.1.4 Attribute Queries .............................................. 19
   2.1.5 Spatial Queries ................................................. 19
2.3 Maintenance and Use of GIS Street Databases ........................................ 20
  2.3.1 Address matching ........................................................................ 22
2.4 Combinations of Functions .................................................................. 22
  2.4.1 Feature-in-Polygon Update ........................................................... 23
  2.4.2 Feature-in-Polygon Analysis ......................................................... 23
2.5 Conclusion .......................................................................................... 23

3. LITERATURE REVIEW

3.1 Sources of Expertise ........................................................................... 25
3.2 Trends in the Use of Computing ......................................................... 25
  3.2.1 Mainframe-Based Computing ....................................................... 26
  3.2.2 Office Automation ...................................................................... 27
  3.2.3 End-User Computing .................................................................. 27
  3.2.4 Decision Support Systems ............................................................ 28
  3.2.5 Re-Engineering of Work ............................................................... 29
3.3 Mainstream Literature ......................................................................... 30
  3.3.1 Raves ......................................................................................... 30
  3.3.2 Reviews ...................................................................................... 31
3.4 School Planning Applications in the GIS Literature .............................. 31
3.5 Information Systems Implementation Literature .................................. 32
  3.5.1 Municipal GIS ........................................................................... 32
  3.5.2 Implementation Problems ............................................................ 33
  3.5.2 Implementation Safeguards ......................................................... 34
3.6 Conclusion .......................................................................................... 34

4. APPLICATIONS OF GIS FOR NEWTON PUBLIC SCHOOLS .................. 37

4.1 Research Framework ......................................................................... 37
4.2 The Master Streets Database ............................................................. 39
  4.2.1 Goals .......................................................................................... 40
  4.2.2 Geographic Information Management ......................................... 40
  4.2.3 Applications of GIS .................................................................... 41
  4.2.4 Information Resources Requirements .......................................... 41
  4.2.5 Procedures .................................................................................. 42
4.3 School Enrollment Forecasting and Redistricting ............................... 42
  4.3.1 Goals .......................................................................................... 42
  4.3.2 Geographic Information Management ......................................... 43
  4.3.3 Applications of GIS .................................................................... 44
  4.3.4 Information Resources Requirements .......................................... 45
  4.3.5 Procedures .................................................................................. 46
4.4 Transportation Management and Planning ........................................ 46
  4.4.1 Goals .................................................. 47
  4.4.2 Geographic Information Management ........................................ 47
  4.4.3 Applications of GIS .......................................... 49
  4.4.4 Information Resources Requirements ....................................... 51
  4.4.5 Procedures .................................................. 51
4.5 Bilingual Program Planning .................................................... 52
  4.5.1 Goals .......................................................... 52
  4.5.2 Geographic Information Management ...................................... 52
  4.5.3 Applications of GIS .......................................... 52
  4.5.4 Information Resources Requirements ....................................... 52
  4.5.5 Procedures .................................................. 53
4.6 Title I Program Administration .................................................. 53
4.7 Conclusion .............................................................. 53
  4.7.1 Benefits of Using GIS ........................................... 54
  4.7.2 Development of GIS Analysis Capability .................................. 55
  4.7.3 Optimization ................................................... 56
  4.7.4 The place of the Computer Analyst ....................................... 56

5. ISSUES IN IMPLEMENTATION OF GIS ......................................... 59

  5.1 Research Framework .......................................................... 59
    5.1.1 User Needs .................................................. 59
    5.1.2 Development .................................................. 60
    5.1.3 Versatility ................................................... 60
    5.1.4 Maintenance .................................................. 60
  5.2 The GIS Streets Database .................................................... 61
    5.2.1 User Needs .................................................. 61
    5.2.2 Development .................................................. 62
    5.2.3 Versatility ................................................... 63
    5.2.4 Maintenance .................................................. 64
  5.3 The Eligibility Database ..................................................... 64
    5.3.2 Development .................................................. 64
    5.3.3 Versatility ................................................... 65
    5.3.4 Maintenance .................................................. 65
  5.4 The City Census and Student Database ....................................... 65
    5.4.1 User Needs .................................................. 66
    5.4.2 Development .................................................. 66
    5.4.3 Versatility ................................................... 66
    5.2.4 Maintenance .................................................. 66
  5.5 The Transportation Database .................................................. 66
    5.5.1 User Needs .................................................. 67
    5.5.2 Development .................................................. 67
    5.5.3 Versatility ................................................... 68
    5.5.4 Maintenance .................................................. 68
5.6 Conclusion

5.6.1 Planned Coordination ........................................... 69
5.6.2 Phased Resource and Application Development .......... 69
5.6.4 Developing Database Management Capacity ............... 70

6. CONCLUSION ............................................................ 73

6.1 Development of Departmental Resources ........................... 74
6.1.1 Electronic Information Resources Management ............... 74
6.1.2 Staff Development .................................................. 75
6.2 Coordinated Geographic Information Resources Development ...... 75
6.2.1 Defined Responsibilities and Standards ....................... 76
6.2.2 Software Independent Databases and Applications .......... 76
6.3 Capacity of Planners to Use Computer Based Analysis .......... 77
6.4 The Three Alternatives Revisited ................................. 78
6.4.1 Large-Scale Municipal GIS ........................................ 78
6.4.2 Consultant-Packaged GIS Solutions ............................. 78
6.4.3 Generic Desktop GIS ............................................... 79

BIBLIOGRAPHY ......................................................................... 81

APPENDIX ................................................................. 84

A Transportation Planning Process ....................................... 84

LIST OF ILLUSTRATIONS

2.1. Graphic Display of Spatial Objects ................................. 17
2.2. Association of spatial objects with an attribute database .......... 18
2.3. Spatial selection of objects across layers ....................... 20
2.4. Graphic street information for Newton .......................... 21
2.5. A close-up of streets from the Newton TIGER file ............. 21
2.6. Address Matching .................................................... 22
4.1. Block-Group level resolution and display of forecast information .. 44
4.2. Mapping of forecasted students' residences .................... 45
4.3. Information flows associated with forecasting and redistricting... 46
4.4. Information flows for planning bus transportation ............. 50
4.5. GIS-produced display of detailed transportation information ...... 51
INTRODUCTION

1.1 BACKGROUND

This thesis is the result of an eighteen-month cooperative research project between the Newton Public Schools, Purchasing and Transportation Department, and the Planning Support Systems Research Cluster at the Massachusetts Institute of Technology, Department of Urban Studies and Planning.

The purpose of the Planning Support Systems Research Cluster is to investigate how applications of computing technology can impact the practice of urban planning. The focus of this thesis is to investigate the issues surrounding implementation of commercially available desktop geographic information systems in municipal government.

Newton is a city of approximately 85,000 people located just outside of Boston. The school system serves just over 11,000 students. The focus on Newton Schools provides a setting in which to explore the capabilities of desktop GIS, the applicability of the tools to a department's planning and information management needs, and the important issues in implementation.

The fact that the city of Newton is in the process of developing a centralized municipal GIS system puts the Newton Schools department in league with departments in many cities which may see the opportunity to
develop their own GIS capability without waiting for the centrally administered GIS development effort to reach them.

1.1.1 Geographic Information in School Administration: Many of the policies and services of school systems are related to the location of residences, schools and boundaries. School assignment according to district boundaries and bus transportation services are two examples of administrative issues which require spatial information. Administering and planning these services can be difficult when the only spatial information the planner has is the street addresses of thousands of students.

1.1.2 Mainframe Computing Applications: School systems have been making use of computing for information management since the use of mainframe computers for record-keeping became practical in the late sixties. After general admissions and accounting, the first applications of computer technology developed for school administration were tools for forecasting district enrollment and managing bus transportation systems using the addresses of students. Of course, applications of computing have developed substantially since the seventies. Computers and applications have become more sophisticated and more accessible.

1.1.3 Geographic Information Systems: A development of particular interest to school planners since the late eighties has been that of geographic information systems (GIS). GIS is a class of information management tool which has functions for computing, storing and displaying information regarding the relationship among spatial entities (Huxhold 1991; Antenucci 1991). The ability of GIS to work with spatial relationships between objects which may be items in separate databases permits an analyst to combine and view many detailed information sources; and administrators can use GIS to update and change databases based upon changed boundaries or observed spatial relationships between students and services.
1.2 ALTERNATIVES

School administrators who are interested in applying GIS to the spatial analysis and administrative functions of their organizations seem to face three main alternatives: to wait for the city, state, or county government to extend GIS services to the schools, to buy a turn-key system development package from a consulting firm, or to use an off-the-shelf desktop GIS package to develop an in-house capability to implement and support GIS applications.

1.2.1 Municipal GIS: The city of Newton has been developing a central GIS system for 2 years, and plans to include the Schools department in the system have been considered, but indefinitely postponed. Municipal GIS projects involve central software and data servers which collect and distribute information from across a network, and typically involve several departments. The software currently used for large-scale municipal GIS is very versatile, but even the simplest application development requires specialized programming.

1.2.2 Consultant Packages: Special-purpose GIS packages especially for school planning have been available since the mid eighties. These packages are intended to make GIS applications accessible to schools by eliminating the need for a GIS-specialist. These 'turn-key' solutions offer complete data compilation services, and custom GIS functions designed specifically for school planning.

1.2.3 Generic Desktop GIS: The nineties have seen great leaps in terms of GIS accessibility. One aspect of this advance has been the development of much better GIS interfaces which significantly reduce the complexity of using generic GIS functions for a variety of problems. Another reason for the increased accessibility of GIS has been the release by the federal government of a GIS basemap containing street information and census boundaries for the entire country. The prospect for non-programmers too access GIS tools may impact the way that municipal GIS extends to peripheral departments.
such as schools, and the development of in-house computing capacity in these departments.

1.2.4 Exploring the Alternatives: How should a municipal department such as Newton Schools deal with the advent of computing tools like GIS. Does the technology have anything to offer, what would be involved in developing the capacity to use this tool? By exploring the development issues of generic desktop GIS packages, this thesis will answer many questions regarding GIS implementations in general, including the other two alternatives.

1.3 Structure of the Thesis

This thesis provides a rationale and guidelines for considering the GIS development path described in Section 1.2.4. The rationale comes from a review of the pertinent academic and professional literature. The expertise and documented experience in the literature provides a model for evaluating the case of Newton Schools. The conclusions reached after this analysis can be applied to school systems and to other municipal departments in similar situations. The structure of the thesis is as follows:

1.3.1 Summary of GIS Functions: The basic functions and capabilities of this class of tools are illustrated. The illustrated examples provide a basic understanding of the tools which desktop GIS provides for capturing, displaying and maintaining spatial information.

1.3.2 Literature Review: Adoption of desktop analysis tools for planning and administration is an area which has been discussed widely in the professional literature. This literature is reviewed to provide an overall perspective of desktop GIS as an aspect of the general trends in the development of computing for management. The literature particularly concerning school applications of GIS will also be covered. This literature review will allow conclusions to be drawn concerning the role that desktop GIS may play in the overall development of an organization’s computing
capability. A rationale for our choice of development path for desktop GIS and an analysis framework can also be drawn from this literature review.

1.3.3 Applications of Desktop GIS for Newton Public Schools: A department considering investing in GIS should consider how GIS tools might be applied, and the resources which would be required. Using Newton Schools as an example, the applications of desktop GIS will be discussed with regard to their usefulness, their data requirements and their operation. This discussion will permit an analysis of the utility of GIS for the department and the issues surrounding its use.

1.3.4 Issues in Implementation and Maintenance: The arrangements necessary for developing and implementing GIS applications will be discussed, again using Newton Schools as an example. The investments in databases, applications and staff skills will be considered in light of the costs, benefits and risks involved. The issues covered in this chapter will allow conclusions to be drawn concerning the roles that department staff, the municipal GIS, and consultants should play in developing departmental GIS capacity.

1.3.5 Conclusion: How should a municipal department proceed in assessing and developing GIS applications when a municipal GIS is on the drawing board? The case of Newton Public Schools can be considered as a model for discussing the issues presented by the opportunities and the challenges offered by this new breed of software products.
FUNCTIONS OF DESKTOP GIS
FUNCTIONS OF DESKTOP GIS

2.1 Geographic Information Systems

Geographic information systems is a class of tools that have a certain set of capabilities. The functions of desktop GIS are a subset of the functions offered by large-scale systems. The functions described in this chapter are the lowest common denominator of GIS functions to be found on any off-the-shelf, custom, or large-scale GIS. For a more complete treatment of GIS functions and analysis see Antenucci (1991, ) Huxhold (1991, ) or Maguire (1991).

Although most GIS include the same set of basic functions this is not to say that they are all equal. Significant differences exist between packages in their interface design, data query interface, and hardware platform. Some GIS offer more sophisticated functions than is thought of as the generic set. For discussions of the differences among desktop GIS products see the recent software reviews in PC Magazine (Kendall 1991) and in Planning, (Van Demark 1992).

2.1.1 Spatial Objects: Geographic information systems are computer systems which help manage information about spatial objects. A spatial object is an entity which can be represented by a point, a line segment or a boundary. Every spatial object can be described in terms of its location in a coordinate system.
A GIS provides tools for creating and altering the characteristics of spatial objects or attaching information to them (see Section 2.2.2). The locations of the objects relative to each other can be used to create new attribute information (see Sections 2.4 and 2.1.5).

2.1.2 Attribute Data: An object may have attribute information associated with it. For example, a student may be represented on a map as a point; attribute information concerning that student may be the student's name, school assignment, age, or any other characteristic of the student which can be expressed in alpha-numeric characters. Line objects may carry attributes for a name, or attributes describing the direction and characteristics of the end-points (e.g. an address-range).

Boundary objects may have the same type of attribute information as point objects, and may carry additional information such as perimeter, area, and properties attributed to the area enclosed by the boundary, such as the number of students with residences inside the boundary. Different packages may call boundary objects by other names, including region and polygon.

2.1.3 Layers and Tables: Attribute data in the GIS database can be separated into different tables. For example, there may be a student table, and a separate school district table. These separate tables can be associated with its own set of spatial objects. These sets of objects can be thought of as map layers which can be displayed at the same time. GIS software can work with the relationships of objects in separate layers.

2.2 Desktop GIS Functions

Desktop geographic information systems offer a toolkit of functions which can be applied to spatial objects and attribute data. These basic functions can be combined in many ways to create applications.

The most basic GIS functions are graphical display of spatial objects, association of spatial objects with attribute data and graphical and attribute queries. Most desktop GIS packages provide other functions which are
particularly useful for working with street information, and other combinations of the basic toolkit functions which are commonly used. These generic GIS functions will be described in the following series of illustrations.

2.2.1 Graphic Display of Spatial Objects: Geographic information systems are capable of storing and displaying information related to spatial objects such as points, lines and boundaries (polygons). This is accomplished by storing the coordinates of locations of the points, the endpoints of lines or the vertices of polygons. Display, and other GIS functions, are accomplished through geographic calculations which infer the relationship between these stored coordinates. In most GIS packages the coordinate information and associated calculations are completely hidden from the user.

Figure 2.1 illustrates the three types of spatial objects used in desktop GIS packages. The listing on the right is the format which a GIS might store the coordinate descriptions of the objects. The GIS toolbox in the upper left-hand corner of the figure has tools for creating and editing each type of spatial object.

Fig. 2.1. Graphic Display of Spatial Objects
2.2.2 Association of Spatial Objects with Attribute Database: Spatial objects in the GIS can be associated with information about the object (attribute information) which is stored in a database. Figure 2.2 illustrates how a spatial object representing a student is associated with a record in a database of information about a variety of objects on the map. Selecting the object on the map also selects the information about that object in the database. Once selected, the attribute information (such as school assignment) for the particular object can be altered. Selections and updates of this type can be performed on several objects at one time.

Figure 2.2 shows how GIS might display a set of spatial objects and a table of attribute data. This illustration is an example of a data layer and a table which contains a variety of different types of objects. Normally a GIS data layer contains only one type of object,

Fig. 2.2. Association of spatial objects with an attribute database

2.2.3 Thematic Mapping: Attribute data can be used to define the appearance of the display of associated geographic objects. For example, points representing students could be colored differently according to the school to which they are assigned. Boundary objects can be shaded according to the population density attributes of each polygon (see Figure 4.2).
Attribute information may also be used to label the displayed objects as shown in Figure 4.4.

**2.1.4 Attribute Queries:** A query is an operation which returns a subset or a summary of information from a database. Attribute queries are used in GIS as well as standard database management packages. Data may be selected from a database by requesting that records in the database be selected if they fulfill some condition specified by the user. Figure 2.2 shows the result of an attribute query which selects all students from a table of spatial objects where the student's name is Monique. Once selected, the objects and their attribute records can be altered, deleted or written to another layer and table.

Attribute queries are the most useful element in the analysis and management of electronic data. Queries can be quite powerful and complex. The best GIS packages use a query building interface based on a relational database model. Queries in this type of system can be created using a standard query form called structured query language (SQL). To become more familiar with query concepts and SQL, see Trimble (1989).

**2.1.5 Spatial Queries:** The relationships between objects in separate layers can be used to perform queries. A spatial query might use a boundary from one layer to select all of the point objects in another layer. Once selected, the point objects can be copied to another layer or have their attribute information altered en masse.

Figure 2.3 shows a spatial query which selects all of the line objects from a GIS street database which fall within a particular boundary object on a school-district layer. All of the selected objects are then updated to reflect the correct district. The same type of query can be made with a temporary boundary area which the user defines for the purpose of the query.
2.3 MAINTENANCE AND USE OF GIS STREET DATABASES

Using the concepts of spatial objects illustrated in Figures 2.1 and 2.2 it is easy to imagine a database of line objects arranged as a street map. The U.S. Bureau of the Census has produced such a database for the entire United States. This computer database is called the TIGER (Topologically Integrated Geographically Encoded Records) files. The TIGER files include information on all of the geographic features which are used to compile the census of population (United States 1989).

Figure 2.4 shows a GIS street map of Newton extracted from the TIGER file of Middlesex County. Figure 2.5 illustrates the geographic and attribute data associated with streets in the TIGER file. Each street segment (a segment is defined as a stretch of road between two intersections) is associated with an attribute database which includes the street name and the address range for each side of the street segment. An in depth discussion of the problems of the 1990 TIGER Files is given in Section 5.2.2.
Issues in Adopting Desktop GIS for Schools Planning

Fig. 2.4. Graphic street information for Newton from the TIGER file of Middlesex County

Fig. 2.5. A close-up of streets from the Newton TIGER file and associated street information
2.3.1 Address matching: GIS address-matching estimates the point location on a GIS street database map given an address. Address matching is accomplished using a computerized street map similar to the one shown in figure 2.4. An address is associated with a particular street segment in the street file through an automatic search for a record in the street attribute database with a matching name, and an address range including the given address. The approximate location of the address along the street link is found by determining the distance between the endpoints proportional to the place in the address range of the street occupied by the address. Figure 2.6 illustrates a small file of students which was geocoded to a street centerline file of Newton. Most GIS packages offer an automated address matching function which will assign point locations to an entire file of addresses.

![Address-matching: locating an address on a GIS street database.](image)

2.4 COMBINATIONS OF FUNCTIONS

Some combinations of GIS functions are so useful that GIS packages have bound them together into single operations. Two of the most useful combination-functions include the function that assigns attribute characteristics to objects according to the boundary in which they are located; and the function that assigns attributes to boundary objects based on summary information concerning objects within the boundaries.
2.4.1 Feature-in-Polygon Update: This function uses an automated process to perform a spatial selection of objects from some object database (see Section 2.1.5) using each polygon in a particular polygon database. As this is happening, each of the selected objects has a piece of attribute information attached to it from the polygon database. This is a GIS function which could update a school assignment for each student based on the school district boundary in which their address falls.

2.4.2 Feature-in-Polygon Analysis: Feature in polygon is a process which uses spatial selection to calculate summary information for all of the objects which are within each boundary in a particular boundary layer. The summary information is attached as an attribute to each boundary in the boundary layer. Feature-in-polygon analysis could be used to make a thematic map with the school districts shaded according to the number of middle school students in each (see Figure 4.1).

2.5 CONCLUSION

As a data management tool, GIS is unique because of its ability to deal with the spatial locations of database objects, and to combine different databases based on the spatial relationships among the objects which the databases describe. The power of GIS lies in the combinations and sequences of operations which can be produced from this simple toolkit. As more spatial and address data is available in electronic form, the number of useful GIS applications increases. The specific advantages that GIS can bring to school planners are described in Chapter 4.
3

LITERATURE REVIEW

3.1 SOURCES OF EXPERTISE

The development of management information systems has been a matter of interest to business professionals and management theorists since computers first began to have potential as accounting tools. GIS is an outgrowth of information technology which escaped the notice of the business community until recently. Because of the responsibility of government for keeping and assessing land information, the pioneering work in GIS development has been done in the public sector. The experience of both the public and private sectors can help to guide the present work; through this understanding we can achieve an understanding of the setting from which the use of computers in management is coming, the direction it ought to head, and how to get it there.

3.2 TRENDS IN THE USE OF COMPUTING

The professional and academic literature concerning trends in information resources management will provide a perspective on the current situation in Newton Public Schools and a basis for anticipating the path these issues
should follow in the near future. The trends involve changes in technology, information resources, and the ability of managers to use computers strategically.

Britton Harris (1967) had predicted that the (then) present environment of computing, which was dominated by specialists working in white lab-coats, would eventually become accessible to planners and administrators; this capability would change the way that planning was done and the ways that decisions were made. In 1982 Richard Nolan outlined his stages of growth hypothesis (Nolan 1982), based on the observation of the use of information technology, information resources and capacity to use computers strategically in business organizations. Nolan's stages provide a useful framework for discussing the development of management information systems; another useful summary of these trends is given by John Rockhart (1992) in the Sloan Management Review.

3.2.1 Mainframe-Based Computing: Nolan observes that the first uses of computing were applications which automated the processing of transactions, accounting and report generation. Naturally, the first uses of computing were simply applications of the computer's ability to store and sort large amounts of data and to print reports. Computer databases were a natural repository for bank records, tax records, and eventually, student registration information. The mainframe computers and their information resources were difficult to access; they were manipulated exclusively by specialists in computer science.

The availability of electronic information resources, developed for record-keeping, soon paved the way to a second stage in the use of computers for management: managers discovered the usefulness of the new electronic information resources for administrative and planning tasks. For example, as a way to catch errors, a banker would conceive an application which makes a report of the largest withdrawals made each day; or a school administrator may recognize the potential of the computer to assign students to school districts based on the students' addresses. These applications, once described
to a computer programmer, would be coded in COBOL or FORTRAN. These pre-programmed analysis tools could be run regularly to produce a standard report. To have a new question answered through such a mainframe database is difficult because of the necessity for custom programming by computer specialists.

Development of management applications for mainframe computers requires either computing-savvy managers, or management-savvy computer technicians. These two classes of people are growing in number as computing becomes a part of a basic education and as pre-computing managers learn how to use computing to improve their organizations, or retire.

3.2.2 Office Automation: A third stage in the integration of information technology began as inexpensive personal computers and user friendly software brought the power of computing to nearly anyone's desktop. The first applications of desktop computing were aimed at automating clerical work--writing letters and keeping ledgers, for example. Office workers also gained access to central databases through terminals which would allow standard reports to be viewed and very simple updates to be made. This is the current stage of information technology integration in many organizations, including Newton Schools.

Many authors have recently noted that the increased investment in computing has not seemed to have an effect on measures of productivity (Brynjolfsson 1992; Ludlum 1990). One reason for this is that most of the computers in offices today are used primarily as typewriters. The number of fonts available to secretaries and the ability to include better graphics in company reports may have improved the quality of reports and the image of some organizations without impacting the bottom line. The mere availability of desktop computers resulting from office automation is expected to have an effect, however, in making the power of computing available, and ready to be put to work as soon as managers recognize the potential (Rockhart 1992).

3.2.3 End-User Computing: The fourth phase of integration of desktop computing into organizations involves a more automated and analytical use
of the information than that occurring in the office automation stage. The ease of use, and greater uniformity among software interfaces, now allows planners and administrators to learn software applications quickly. These computer-savvy managers are learning to organize, access and manage automated information resources quickly without reliance on computer specialists. This is the essence of end-user computing.

The development of desktop applications that make use of the computer's ability to store, sort, access and print from a department's information resources marks a step beyond the simple automation of previous clerical tasks. Not only will people who are not computer professionals be able to manage information more effectively, but end-user database management is producing new information resources which can be used in a multitude of ways.

The creation of some departmental databases in the user environment is one aspect of end-user computing. Another is the client-server computing model. In this model, a central database can be accessed across a network by several users. The management functions which can be applied to central databases using desktop computers are much more flexible and useful than those which are permitted by mainframe terminals.

Increasingly, managers and office workers will find it necessary to learn the mechanics of handling and designing electronic information. Joseph Ferreira (1990) has written a useful primer on the levels of knowledge which managers will find useful for organizing and accessing useful information without having to go through a specialist. The building of databases in dispersed locations is a phenomena which is beginning to be seen as an opportunity to strengthen organization-wide resources. Bijan Azad (1987) highlights this aspect of end-user computing and proposes strategies for coordinating decentralized databases and users.

3.2.4 Decision Support Systems: It wasn't long after electronic information became available on mainframe computers that managers discovered ways to use it strategically. The same process is happening with
desktop data access. Only now the tools are under the direct control of managers and planners. The new decision support tools are much more flexible in their interaction with data, and also in their ability to use graphics to visualize and manipulate the data.

Decision support systems range from simple spreadsheet applications to elaborate software systems involving complex models and computer graphics (Turban 1990). Two of the chief problems in developing decision support systems are access to up-to-date information in computer readable form, and the problem of customizing practical computer tools; both of these obstacles are becoming overcome. More information is being maintained in automated form in the user environment, and digital data is being made available from central file-servers through local and wide area networks. Additionally, tools for using electronic data strategically are becoming much easier to customize and to combine into user-created decision support systems made of multiple off-the-shelf software packages.

New commercial desktop GIS products are capable of being customized and integrated with other software as part of modular decision support systems (Van Demark 1989). There is not agreement, however, on how custom-tailored such a system should be. Francica (1992) has a vision of desktop GIS tools aimed specifically at specific tasks, while Ferreira (1990) suggests that over-customization of analysis tools with pre-programmed functions for specific tasks reduces the flexibility of the tool to deal with unexpected situations. The movement of data management to the desktop means that planners should not be limited to finding answers which could have been anticipated in advance by computer programmers. The true potential of decision support systems will be realized when decisionmakers command the skills necessary to use the full power of data access and analysis tools.

3.2.5 Re-Engineering of Work: As the shift from office automation to end-user computing involves the diffusion of database management concepts throughout the organization, the application of decision support systems
involves a new way of organizing tasks. The hierarchical layout of organizations is to a large degree the product of a division of labor with regard to information collection, processing, analysis, and decisionmaking. The removal of the need to have different people at each one of these phases will eventually lead to a reduction in the number of levels in hierarchical organizations (Drucker 1989; Zuboff 1991). To truly reap the benefits of computing power, each business function will need to be evaluated in light of the opportunities presented by information technology (Markus 1983; Somers 1989).

3.3 MAINSTREAM LITERATURE

There is no shortage of literature expounding the potential of desktop GIS. Not only vendors, but also academics and software reviewers are enthusiastic about the things that planners and administrators can now do if they will only buy GIS. The focus of attention in most of the literature likely to cross the desk of a school administrator is on features and exotic capabilities. There has been very little written about the real concerns surrounding implementations of desktop GIS applications.

3.3.1 Raves: There are two types of article about desktop GIS which are likely to cross the desk of a school administrator; there are the "Welcome to the Future" sort which are about desktop GIS in general. "The Next Step is Called GIS" is the title of a recent special issue of American Demographics (Exeter, et al 1992). and "Desktop Mapping: Wave of the Future" (Van Demark 1993) was a recent cover story of Planning. The purpose of these articles is to bring the potential of GIS to the attention of business-people, consumers and planners. In the 25 page American Demographic supplement there is one page on the practical problems of implementation (Craft 1992).

"Integrating data is the first step. Once integrated, you can analyze." (Frost 1990 pg 17) This is the simplistic way that most of these general GIS reviews discuss the technical problems of implementing and supporting GIS. Highlighting opportunities is the goal of these articles, not finding problems.
The message of these articles is "GIS is full of potential, and has become much less expensive since the release of the geographic products of the 1990 census." Implementation of these tools for sustainable organizational support is not seen as a big problem yet, because few people have tried it.

3.3.2 Reviews: The second type of article about desktop GIS in the popular/professional press is the software review. Two recent examples, one in *PC Magazine* (Kendall 1992), and another in *Planning* (Van Demark 1992) put various desktop GIS software through the paces using canned datasets. These reviews are useful for learning about the differences among software packages in terms of functionality and ease of use, issues which are indeed important.

If you have a one-time research project in which data can be entered into a GIS, processed and forgotten, then software reviews can be your primary investment guide. If you are the manager of an information gathering and processing organization, the software is only one of many more complicated issues.

3.4 School Planning Applications in the GIS Literature

There have been few entries in the professional literature regarding school planning applications of GIS. What articles have been written do not offer any deep insight into development issues, implementation issues or coordination with a larger municipal GIS.

Bailey and Lewis (1990) present a demonstration of the capabilities of Arc/Info GIS software to perform interesting applications involving finding the shortest paths for school bus routes. (Incidentally, their proving-ground was also Newton.) This work is an interesting demonstration of a software feature, but it unfortunately sheds little light on issues of developing the data, the applications for managing it, or the organizational arrangements which would be necessary for using these applications. In fact, finding the shortest path for a bus-route is a very small part of the actual problem of
managing the transportation planning process (See Appendix A). A very similar article has been written by Jamploskey (1991).

The most recent and most interesting article concerning GIS applications for school planning has been written by Derek Graham (1993) of the State of North Carolina Department of Public Instruction. This article describes a state program to automate school transportation planning using a special-purpose school-planning software package. This article is most interesting because it discusses an actual implementation, some problems, and results.

The implementation of the North Carolina project involved the creation of a GIS street-map of the whole state (this was before TIGER). Because of software limitations the different counties were done at different scales. This inconsistency has created the need to start a pilot program to replace the map bases. Each of the 105 school districts which are using this software has a full-time coordinator or operator to run the software.

3.5 INFORMATION SYSTEMS IMPLEMENTATION LITERATURE

Although there is not a lot of professional literature concerning the implementation of desktop GIS systems for school planning tasks, a lot can be learned from the experience of municipalities, like Newton, which are attempting to implement large-scale GIS projects. The implementation issues of management information systems in general are also applicable.

3.5.1 Municipal GIS: Geographic Information Systems hold great promise as a tool to help city governments organize their information resources and coordinate their programs (Huxhold 1991; Antenucci 1991). Many cities are developing central GIS systems that will serve many city departments. These enterprise-wide municipal systems are usually based on large-scale GIS packages which run on engineering workstations. The software alone costs about $17,000.
While this price tag seems to put these systems in a different league than desktop GIS, there are good reasons to believe that the implementation issues of large-scale systems are related to those of desktop GIS: both types of systems involve the integration of data from a variety of sources for planning purposes; in both cases (desktop and large-scale) the cost of the software is insignificant when compared to the other arrangements which are necessary (Thompson, 1989). Both desktop and large-scale systems are likely to be merged in a client-server relationship as GIS software and wide-area networks become more accessible (Van Demark 1989).

3.5.2 Implementation Problems: "(E)ffective adoption of microcomputer technology often depends more on organizational and political factors than on technical issues of hardware, software, and the like. (Klosterman 1992, pg 253)." A new genre of literature has emerged in the professional literature of MIS and GIS which is marked by litanies and laundry lists of problems encountered in the course of one or more implementations. Generally speaking, the risks fall into two categories: complete obsolescence of investment, or failure of the system design to recognize or live up to its potential as part of the organization's information resources development. The following is a general summary of GIS implementation problems:

From Somers (1989); Croswell (1989); Markus, (1983).

- Poor design -- leading to unmanageable, obsolete systems and data.
- Mis-match between the requirements of the technology and the work and the cognitive style of the operators or their manager -- leading to poor maintenance, obsolescence.
- Lack of ability to obtain necessary cooperation for data and standards -- leading to redundant, incompatible systems and information, and unfulfilled potential.
- Lack of long-range planning -- leading to obsolete systems, data, and unfulfilled potential.
- Employee turnover due to high demand for skilled workers -- leading to loss of training investment, knowledge.
3.5.3 Implementation Safeguards: Of course, no group of professionals and academics would be completely pessimistic. Their literature also offers pointers to success.

From Markus (1983), Zuboff (1991)

- Establish high level support, mandate for interdepartmental cooperation.
- Assign a project manager.
- Assess needs, develop a long-range plan.
- Select users carefully or let them self-select, involve users in design process, foster a creative environment.
- Consider political, social, personal impacts of systems.
- Provide opportunities, incentives to learn.

These recommendations are easy to make, but extremely difficult to accomplish without active participation of the upper levels of management of all departments (as will be illustrated in Chapter 5).

The most useful recommendation for the purposes of this thesis will be the long range plan. An outline of the essential elements of a long-range plan for GIS implementation is given by William Huxhold (1991). Huxhold’s suggestions for such a plan include:

- Obtain high level organizational support.
- Identify all possible applications.
- Prioritize applications for orderly implementation.
- Obtain maximum benefits system-wide.
- Identify resource requirements system wide (no surprises).

3.6 Conclusion

As organizations and computing technology develop, more people are gaining access to computers. In the development of mainframes and desktop computers the storage and retrieval of information has been the first contribution of computing to the improvement of organizational processes. As electronic databases are built, and managers understand how they can be
used, the information resources are applied in strategic planning and analysis. The overall trends in the development of computing and organizations is not a matter of revolution, but one of an evolution of technology, information resources, and management skills (Norman 1991).

Desktop GIS is not software like word processing packages or spreadsheets. The common packages made familiar in office automation were analogs to familiar manual processes--typewriters and ledgers. Word processors and spreadsheets produce end-products as far as electronic information is concerned. GIS works in the stream of electronic information resources, incorporating and combining useful data from the organization's databases, combining separate resources, making them available for analysis, altering them based on decisions, and returning the information to the stream. The only old-fashioned analog for desktop GIS would be very timeconsuming pin-mapping and cartographic analysis which very few people have had the time or the training to do before now. Analysis of data with GIS represents a new type of work for most people.

This new type of work which sits at the end of a long period of evolution of technology, electronic information resources, and management skills. It is not surprising that implementations of GIS work out better in some organizations than in others. In order to guide and safeguard the investment in information resources, staff skills, and software, it is necessary to assess the current situation and plan GIS implementations carefully. The next two chapters will constitute such an assessment and plan.
4

APPLICATIONS OF DESKTOP GIS FOR
NEWTON PUBLIC SCHOOLS

Chapter 2 outlined the functions that GIS offers for automating complex geographic data management tasks. The literature review in chapter 3 suggested that the work of administrators and planners will eventually be affected by a greater accessibility to complex, detailed information and the availability of tools which will help to exploit this resource. Desktop GIS represents such a tool. How would GIS affect the work of school planners and administrators in Newton? Professionals in the development of information systems recommend that systematic study of planning processes and potential applications be performed to answer this question. This chapter will be such a user needs assessment for Newton Public Schools.

4.1 RESEARCH FRAMEWORK

In order to determine the opportunities that desktop GIS may offer to planners and administrators at Newton Public Schools the procedures which call for managing spatial information were investigated. This investigation involved in-depth interviews with several professionals at the Education Center in Newton. The aim of the interviews was to get an understanding of the goals of each planning or administrative process involving spatial
information, and the spatial information management procedures. In all, eight professionals were interviewed:

1. The Coordinator of Transportation
2. The Research Assistant to the School Planner
3. The Director of the Administrative Technology Center
4. The Coordinator of Special Needs Transportation
5. The Coordinator of Transportation for the Metropolitan Educational Collaborative (METCO).
6. The administrator of the Bilingual Education program
7. The administrator of the Pupil Services Office
8. The administrator of the Title I federal grant program

The investigation of goals for planning process involved more than the reasons for the individual procedures. Because of the possibility that a change in the ability to process information may remove barriers which formed the goals in the first place, an in-depth understanding of the organizational context and mandate for each task was sought. An example of the type of information which was gathered in these interviews is given in Appendix A.

The practicality of applying GIS is based on two issues: the fit between the functions of desktop GIS and the information management tasks necessary to meet the organization's goals; and the practicality of assembling the information resources which would be necessary to make a GIS application sustainable.

Desktop GIS was chosen as the platform upon which to study applications for school planning because of the distant possibility of linking with the city's large scale system and the lack of funds for buying a turn-key consulting package. It was also predicted that a review of the issues involved in implementing from-the-ground-up desktop applications would be largely the same in any case.

The analysis of planning and administrative functions at Newton Public Schools revealed two sets of spatial planning problems which are central to school planning. The first is enrollment forecasting and district planning. The second is planning and management of school bus
transit. These core functions are linked by a shared dependence on a spatial eligibility database (the master streets database). The maintenance and use of this database presents a third possible GIS application. The user needs assessment revealed several additional possible applications of GIS. Two of them -- Title I eligibility assessment, and bilingual services planning, could be considered spin-off applications from the core applications because they would require little additional data or application investment beyond what would ordinarily be expected without GIS.

Two other applications: special needs transportation, and transportation for the Metropolitan Council for Educational Opportunities (METCO) were noted but not considered part of the core package due to the fact that GIS applications for these functions would require the building of a regional information resource. The issues in applying GIS to the core functions and to the spin-off applications are representative of the general issues of GIS application development. Understanding these core issues will provide administrators with the background to evaluate the benefits and the requirements of applying GIS to these and other areas.

The remaining part of this chapter contains four sections describing the master streets database, the two core planning processes which it supports; and the spin-off applications. For each section, there will be three subsections: 1). a discussion of the goals which will focus on the goals of each process; 2). a summary of the current spatial information management procedures which will provide a benchmark for evaluating the impact of GIS applications; 3). a discussion of the application of GIS functions describing how the process or outcomes would be affected through the application of the basic GIS functions (see Chapter 2); and 4. an inventory of the information resources necessary for each GIS application.

4.2 THE MASTER STREETS DATABASE

The most central spatial data management function at the Newton Public Schools involve the maintenance and uses of the master streets database.
This database consists of a single computer file which records the school eligibility and bus-stop assignment for every address in Newton. The file uses ranges of addresses to differentiate pieces of streets which may lay in different eligibility areas. This database is maintained in the Administrative technology center and updated by the transportation coordinator.

4.2.1 Goals: The primary function of the master streets database is to provide an official record of the eligibility of residences for assignment to a particular school, or eligibility for transportation. These are matters of keen interest for parents and realtors. A document which explicitly and definitively records the eligibility of any house is necessary for providing information to the public and more importantly, for avoiding disputes. If district boundaries were described in terms of lines on a map or actual surveyed boundaries there would be endless disputes over the relative locations of houses, or parts of houses and the boundary lines. The expression of eligibility in terms of addresses eliminates most if not all of these disputes.

4.2.2 Geographic Information Management: A secondary function of the master streets database is as an aid to simplifying geographic complexity. As an automated reference for address-eligibility, the master streets database can be used to determine the school eligibility or bus-stop assignment of any address in Newton through an automated process. Such a process is used by the Administrative Technology Center (ATC) to record the assignment of each student in the student database, and to create summaries of information by bus-stop, bus run, and school district. The Newton city census (a municipal count of households and population) can be processed in the same way. These summarizations are extremely useful for the district planners and the transportation coordinator, who would otherwise be faced with having to deal with geographic complexity through long lists of addresses.

Making changes to the master streets database is very intensive in terms of managing geographic information. These changes must be posted whenever districts or bus-stop service areas are re-aligned. The procedure for
doing this consists of translating a marked map to a list of affected addresses, and making revisions to the appropriate fields and records in the master streets database. This is accomplished by use of the Polk Directory which is a reference for street addresses and cross-streets. The changes are marked on a print-out of the master streets database; this marked copy is used as a guide for typing changes one record at a time into a mainframe terminal. For the opening of Bigelow Middle school this year the reassignment of the affected streets for the school districts and re-defined bus stop scheme is estimated to take approximately 80 hours of the transportation coordinator's time and 40 hours for the data-entry person.

4.2.3 Applications of GIS: A desktop GIS application for helping to update the master streets database would significantly reduce the amount of manual searching through print-outs, maps, and address resources for the person involved. Rather than having to deal with every street segment whose eligibility status has changed -- updating assignments and splitting or reuniting address ranges; the user of a GIS application could affect the update by simply adjusting the relevant boundary and performing attribute queries.

In addition to reducing the complexity and time involved in updating the master streets database, a GIS application of this type would allow the resulting database to be checked visually by highlighting streets on the map according to eligibility assignment. Using the current procedures, errors in the master streets database can only be found through trial and error.

4.2.4 Information Resources Requirements: This application would require two types of GIS data: streets and boundaries. The streets database will have to be correct to the extent that it includes every street with spellings which are compatible with the street spellings used in the student database and the city census. The address ranges of the street segments would need to be checked and corrected as needed for streets which are divided by boundaries.
GIS Boundaries will need to be created. There will need to be a separate boundary database for school assignment and transportation boundaries for each type of school (elementary, high and jr. high). Transportation eligibility and bus-stop assignment can be conveyed through one boundary file per school type. The necessary boundary databases could be created by drawing boundaries around groups of streets selected based on information which is contained in the present master streets database.

4.2.5 Procedures: The GIS functions which would be required for using desktop GIS to update the master streets database would be feature-in-polygon selection, and fairly complex attribute queries. The general steps for updating the database after a change in any boundary would be as follows:

1. Map the streets and applicable boundary layer using the GIS.
2. Change the boundary on the computer screen to reflect the new alignment.
3. Check the address ranges of the streets which have been newly crossed by the changed boundary (the Polk directory can be used for this).
4. Use feature-in-polygon up-date (see Section 2.4.2) to correct the school assignments of all the street-segments except those which have a different assignment on the even and odd sides of a street (this is accomplished with through the update query).
5. With a complex attribute query, select the highest and the lowest address for each street which appears in more than one school district to create a list with the minimum number of records.
6. By coloring the street segments according to their school assignments, check the new street assignments.
7. Write the new master streets database to a disk and give to the ATC for use in their applications.
8. Produce maps of the new district and transportation boundaries.

4.3 School Enrollment Forecasting and Redistricting

School enrollment and redistricting is carried out in the office of the assistant superintendent for operations and planning. Authority to approve proposals for redistricting belongs to the school committee.

4.3.1 Goals: Anticipating and meeting the demand for school services is a major part of the responsibilities of the school planner. School enrollment is forecast five years in advance using information from the city census for
elementary school forecasting, and the student database for forecasting of enrollment of grades 5 through 12. A cohort survival method is used to determine the portion of each age group which is expected to advance into higher grades in the public school system. The goal of forecasting is to determine the most efficient arrangement of facilities and districts to meet the current demand in each year and to anticipate the need for future years. Redistricting proposals are sometimes the product of forecasting exercises—when an overload, or a downtrend in demand is anticipated, a school opening, consolidation of districts or a simple adjustment of boundaries may be proposed to the school committee.

4.3.2 Geographic information management: Standard year-to-year forecasting is assisted by the address matching program which is run on the ATC mainframe (see Section 4.2). The city census and the student database are matched with the eligibility information in the master streets database and a report is generated which summarizes the number of people in each critical age-group who live in each district. This enables the school planner to watch growth rates in a district-by-district basis. When it appears that a school may become over or under-enrolled, remedial actions can be proposed.

When an adjustment of district boundaries is proposed, the proposal evaluation process involves counting the number of children of a particular age group within the area to be redistricted. This process currently requires a query to be programmed and run on the ATC mainframe. These queries often take days to fulfill due to the busy schedule of the ATC staff.

The type of query used to evaluate a redistricting proposal involves the ATC address matching capability. The address ranges of streets affected by the redistricting must be specified by someone; the Polk directory and Newton street map are used for this. Then these address ranges are inserted into a COBOL program written and maintained by the ATC staff, and the student database, or city census is searched for students of the particular age-groups of interest who live within the affected area. The result is a
count, or possibly several counts, which will be the base-line for a forecast of the contribution of this area to future class-sizes.

4.3.3 GIS Applications: The application of desktop GIS to district planning would give the planners a much finer view of the growth patterns of Newton with respect to different age groups, and precise counts of students (or future students) within proposed redistricting areas. Alternative redistricting options and counts could be completed by the planner in minutes.

Figure 4.1 shows a map which displays the change in enrollment predicted over a five year period. The changes are mapped by census block-groups. With such a picture of the specific areas in which growth or attrition is particularly strong, proposals for opening schools or adjusting districts could be more directly targeted to account for high or low growth areas. A map of this kind could also be produced using the U.S. census--a capability which would be very useful if the city census were discontinued.

Fig. 4.1. Higher resolution forecasting and districting information

Another useful tool for guiding adjustments of districts would be a map showing the actual locations of the projected students as shown in Figure 4.2. This map of projected students could be used to actually count the students within a proposed addition to a school district. District boundary change
proposals could be made based on knowledge of where students live. This ability would save time and remove the guess-work from redistricting.

Figure 4.3 illustrates the path which information must follow using the current system, the right-hand side shows how the system would work if desktop GIS were implemented. The hands-on access to information allows the planner herself to answer redistricting questions. This new ease in querying would ultimately lead to more alternatives being considered, and ultimately better planning.

4.3.4 GIS information requirements: The GIS applications for forecasting and district planning would require a piece of the student database with addresses and year of graduation or age, and a file from the city census containing addresses inhabited by young children. These two files would need to be completely address-matched against the GIS street database. This application would require the same street and boundary databases which were described in Section 2.3.
Fig 4.3. The information flows associated with forecasting and redistricting, before and after adoption of GIS.

4.3.5 Procedures: The map of projected change in enrollment by block-group can be made using the student database, or the city census. This application uses attribute queries and feature-in-polygon analysis. For the junior high projection (see Figure 4.2) the student database was used to count the current junior high school population, and the first through third graders (who are projected to be in junior high within 5 years). (The same procedure could be performed for pre-school children using the city census.) The steps are as follows:

1. Use attribute query to create two new tables, one containing the present junior high students, another containing the students projected to be in junior high in 5 years.
2. Use feature-in-polygon analysis to count the number in each selection table by block-group. Create a new table with the block-group-ID and the number in from each of the selection tables per block group.
3. Create a new column in the table and update it with the percent change. (If there is an additional growth or attrition factor which is applied in forecasting, it could be applied here.)
4. Map the block groups according to the projected change.

The application for determining the effects of redistricting would involve attribute and spatial queries. The steps for this application are as follows:
1. Use attribute selection to create a new table which includes the classes of students which are of interest (e.g., sixth graders).
2. Use polygon selection to select and count the number of students in the area of proposed redistricting.
3. Produce maps for communicating the proposed change and evaluation to the school committee.

4.4 BUS TRANSPORTATION MANAGEMENT AND PLANNING

Bus service is managed by the transportation coordinator who answers to the assistant superintendent for planning and operations.

4.4.1 Goals: There are approximately 4000 students who are eligible for regular school bus transportation within their assigned school district. The transportation coordinator is responsible for seeing that these students receive transportation as efficiently as possible. This job demands assessing the demand for transportation each year, adjusting the bus-stop locations and the areas served by stops, arranging bus-runs and schedules as necessary, and production of information for drivers, school administrators and the public.

The transportation coordinator must produce driver directions which detail all of the stops and runs in the sequence that the drivers encounter them. Bus schedules, provided to school administrators, contain all of the information necessary to determine the pick-up and drop-off times for any stop, and are arranged by school. The master streets database is kept up-to-date concerning the ranges of addresses which are assigned to each stop. The same manual process is used here as was described in Section 4.2.

4.4.2 Geographic information management: The transportation management routine for in-district students begins each year with the production by the ATC of a bus-loading report. This report is the result of assigning each of the students to bus stops according to their school and their eligibility for transportation. The eligibility determination and stop assignment is made through the mainframe address-matching procedure explained in Section 4.2.2. The report summarizes the number of students
assigned to each stop, and tabulates the number of riders for each bus-run. This information is used by the transportation coordinator to assess any possible overloads or to evaluate the potential for consolidation of stops or runs.

By this procedure, the transportation system changes incrementally, year by year. If a stop is eliminated, or is exchanged between runs, the schedules, directions and master-streets database will be changed. In order to assess the possible effect of changing the schedule of one or more runs, a Gantt (time bar-chart) is produced which enables the coordinator to see schedule overlaps or possible gaps which may permit consolidation of runs. One bus has been eliminated from the system since the present scheme of stops and runs was set up. In normal times, the bus transportation system is fairly stable.

The mainframe programs that assist with management of the transportation system apply only to in-district students. There are about 400 students who are transported to schools out of their district. These are the private school students, and participants in the bilingual education program. Because these students are more widely dispersed, they cannot be assigned to bus stops and routes using the structured procedures used by the mainframe to assign in-district students to stops and runs.

While the bus system changes only incrementally in normal years, the opening of a new school (as is happening this year), a major redistricting, or a change in eligibility policy make for drastic changes to the stops, runs and schedules. These situations represent a different planning role for the transportation coordinator which involves major reconstruction and evaluation of the transportation system. Even when not made necessary by such circumstances, it is quite possible that more frequent restructuring of the routes would be done if more information were available and tools existed for assisting with the complex data management involved. Currently, the primary tools for investigating alternatives in the transportation system are
the transportation coordinator's experience and knowledge of the streets of Newton and the mainframe address-matching function.

In preparing for the opening of the new middle-school, the transportation coordinator would begin reconstructing the system by placing bus stops in strategic locations. In order to assess the loads at these stops, the master streets database would need to be updated to reflect the new stop service-areas, and an address-matching run made on the ATC mainframe. The number of eligible students would be reported for each stop. Using these figures, the transportation coordinator would string the stops into runs appropriately; or if necessary, adjust some of the stops and adjust the streets database again. The change from junior high schools to middle schools means that sixth-graders will be transported to a different set of schools. The increased demand for buses for servicing the new middle school will also affect the transportation for elementary and high-school districts.

When stops, runs and schedules are designed in which each bus is near capacity, and there are no large slots of idle time for any bus, the essential documentation is updated and distributed.

4.4.3 Applications of GIS: Using off-the-shelf functions of desktop GIS the transportation coordinator will have a much finer-grained and more direct grasp of the details of the bus-transportation system. Rather than depending on the bus-stop level reporting provided by the ATC, the coordinator may view the locations of each student eligible for transportation (see Figure 4.5). Rather than having to adjust the eligibility area for a bus-stop by updating the master streets database--and having to wait at least 24 hours to find out the results of this change on the bus loadings, the coordinator can move the boundary of the eligibility area on his computer screen until the desired number of students has been included or excluded.

Figure 4.4 shows two information flow diagrams that illustrate the more efficient access and update of information when desktop GIS is used to manage the bus transportation system. The planner has immediate access to a database of bus schedules and bus-stop eligibility while he is analyzing the
system. Changes made to the boundaries, stops, and the bus runs during planning would be directly saved to the transportation database which could be used to produce the driver directions automatically. The bus schedules and Gantt charts of the tours for each bus could also be created from this database. The ability to visualize, and directly manipulate very detailed information about the bus system will enable the transportation coordinator to try many more alternatives than he is able to presently. It is quite likely that this control over information will lead to more creative and efficient solutions.

In the new procedures, the ATC still plays a role as an information provider, but the transportation planning functions are all done by the transportation coordinator. Elimination of the need to update the master streets database in order to count the number of students in a stop-service area will save days of waiting time.

In Figure 4.5, attribute selection has been used to map the students eligible for transportation to a particular school. The bus stops are mapped
with shapes which reflect the bus which services the stop. Information on the number of eligible students (calculated by feature-in-polygon selection) are shown next to the stops. The number of students who were recorded as actually riding are also shown. Other attribute information such as the arrival times for each stop could also be displayed.

![GIS-produced display of detailed transportation information](image)

**Fig. 4.5.** GIS-produced display of detailed transportation information

### 4.4.4 GIS Information Resources:

The information resources needed for using GIS for transportation planning would include the boundary and street databases described for the master streets database application (Section 4.2). The address-matched student database would also be required. The new data resources needed for this application would be a transportation database and a set of spatial objects representing stops and runs.

### 4.4.5 Procedures:

There are many questions that the transportation coordinator might want to answer using GIS. Following is one possible set of steps which would be followed in a reconstruction of bus stops, routes and schedules.

1. Map the streets and transportation eligibility/bus-stop service area boundaries for middle schools.
2. Use attribute query to map the students for a particular middle-school. Using the number of students selected, estimate the number of busses which would be necessary.
3. Create line objects representing bus routes along likely streets such that each eligible student is less than the maximum walking distance from one of the routes.

4. Place point-objects on the map representing bus-stops.

5. Create boundary objects representing bus-stop service areas assign students to stops using feature-in-polygon selection and update. Count the number of assigned students per stop and per route.

6. Adjust as necessary.

7. Assign estimated arrival times times to bus-stops.

8. Update transportation database to reflect new stops, runs and times.

9. Update the master streets database to reflect the new stops using GIS (see Section 4.2.5).

10. Produce Gantt charts and adjust bus arrival times and reconfigure bus runs among buses as necessary.

4.5 **BILINGUAL PROGRAM LOCATION**

GIS functions can assist in many other planning applications at the school system. The planning of bilingual program location is one.

4.5.1 **Goals:** The coordinator of bilingual services is interested in locating her specific language programs near the homes of most of the students which participate in the program. This has benefits in the efficiency of transportation, and also assures that the students have a greater chance of becoming familiar with the mainstream students in their neighborhood.

4.5.2 **Geographic Information Management:** Currently, the locations of students of a given language are determined with respect to the existing school districts. This is determined with manual searches of the master streets database for each of the 400 bilingual students. The program is located in a school which seems to be central among the districts which contain the majority of the students of that program's language focus.

4.5.3 **Applications of GIS:** GIS address-matching will not only make the process of locating the students easier, but will permit finer-grained analysis than the school district counts which are currently used.

4.5.4 **Data requirements:** The primary resource necessary for this procedure is a computer file with the addresses and language of all of the
bilingual students. The GIS street database would permit the address matching and mapping of a file of bilingual students' addresses.

4.5.5 Procedures: The procedures here are the same as those listed for redistricting, except that the attribute query is based on grade and language.

4.6 Title I Program Administration:
This is a very simple spin-off application. The Title I program allots a grant for the school districts in towns that are above average with regard to the number of poor students in each district. The person in charge of this program receives a list of poor families from the welfare office which she assigns to school districts using paper maps and the master student database. She then calculates the percent of poor students in each district, and determines the districts which are below average.

To locate approximately 200 poor families takes approximately 6 hours. This could be accomplished in a few minutes using a desktop GIS with a street database. A requirement would be that the information from the welfare office were available in a computer text file; given the present proliferation of desktop data management tools this is presumed to be likely.

4.7 Conclusions
From the evaluation of present planning goals and tasks and the description of GIS applications, it is clear that GIS will improve the ability of Newton Schools to plan and provide services. Before long, planners, decisionmakers and the public will expect tools such as GIS to improve the access to information and the responsiveness of organizations.

Utilizing these tools, however involves a new type of analysis which is based upon a definition, calculation, display and manipulation of information through computerized processes. The development of these skills in the planning staff of the organization will be an important part of realizing the potential of tools like GIS.
The investment in information resources which would be necessary to implement GIS applications will be discussed in the next chapter.

4.7.1 Benefits of Using Desktop GIS: The adoption of desktop mapping tools for assistance with school planning will provide several advantages over the current procedures. Some of the advantages are increases in productivity of staff, more efficient allocation of services, improve the responsiveness and quality of service. Ultimately, the planners, the school committee, and the public should have more confidence in decisions which are made with reference to this much more detailed information. In Summary:

1. GIS allows a much more efficient processing of spatial information saving weeks of searching through the master streets database, the street map and the Polk Directory. These searches, for updating the master streets database, and for constructing redistricting queries will be processed by the GIS by the simple adjustment of a boundary by the planner.

2. GIS allows a much finer-grained analysis of the locations of students. The current address-matching capability of the ATC allows only district, or bus-stop counts. GIS can show the location of any set of addresses, and provide summaries for any small area defined by the user.

3. Planners, with visual access to detailed information for analysis should have a much better understanding of the changing circumstances hopefully resulting in more responsive, effective plans.

4. The process of answering questions from the public or the school committee about important planning details using GIS is much quicker and simpler. Being able to answer her questions without leaving her chair, the planner will be able to perform a much more thorough analysis.

5. Planners, decisionmakers, and the public will be more confident in decisions, knowing that many more proposals and alternatives were valuated because of improved access to information.
6. The ability to visualize, comprehend, evaluate, and manipulate complex information about the bus transportation system will save time in the transportation planning process, leading to more responsive, targeted transportation solutions. Ultimately this will result in cost savings.

4.7.2 Developing GIS Analysis Capability: Each of the applications described in this chapter involves a combination of the basic GIS functions of attribute query, display of spatial objects, graphic selection, etc., As described in Chapter 2. Applying these procedures takes training, practice, a desire to learn, and a tenacious attitude concerning technical problems. Finding and supporting the right individual for this work is the most critical task in applying GIS.

This need raises several questions: Can the analytical procedures be made simpler through automation or computer optimization? How should computer analysts be integrated into the organization?

4.7.3 Automation: Processes which can be automated are those which are structured enough to be anticipated weeks in advance of the actual application. The most obvious automated applications are those designed to help the planner select and display all of the information which would be typically necessary for planning districts or transportation for a given school. Automating this process would involve stringing together the queries that a user would make to select the applicable students, boundaries and bus routes. This kind of query automation can be carried out by a user of most standard off-the-shelf GIS packages by setting up the information and saving it as a workspace or macro command file.

To query, display, manage, and manipulate data in every possible way which a GIS user needs or might like to do, however, can never be able to be completely automated. No matter how sophisticated the pre-planned automation of a GIS application, without a facility and operator which allows for creating custom queries and displays the system would be obsolete very soon.
4.7.4 **Optimization:** Optimization is another form of automated process which is not part of the standard tools of most off-the-shelf GIS packages. Applied to redistricting or transportation planning, these programs find nearly optimal solutions for planning goals which are stated in terms of quantitative and spatial constraints.

The use of computing to find optimal, or near optimal solutions, to problems involves a systematic trial and elimination of alternatives until a degree of certainty is reached that no better solution can be found. It is fairly simple to devise a computer program to find the shortest path between two points, more difficult to devise a program which will find the best route around a group of points. Programs to find nearly optimal solutions to transportation systems where bus schedules are involved are extremely complicated, especially if one wants to experiment with combining schools into single bus routes.

Of course, the application can only use information which has been created in a computer database to find its solution. Normally, the optimal solution which is arrived at by the program is treated as a first pass, and subjectively adjusted by the operator based upon his knowledge of real constraints which are non-quantitative, or otherwise not in the database.

Optimization may be a nice feature, using it will probably quadruple the cost of the software and data requirements. In very complex situations such as where undistricted school choice and transportation is provided to a large number of students over a very wide area, optimization may be warranted. In Newton the access to automated processes for planning transportation or redistricting in the setting of Newton Schools would probably not produce better outcomes than an experienced planners using standard GIS tools (Ziering 1993).

4.7.5 **The Place of the Computer Analyst:** Most of the benefits of using GIS for school planning come from removing the obstacles between planners and information. From this it follows that the GIS analysts should be planners themselves. Of course, this transition will not happen overnight.
The planners will need to be trained, or support staff will need to be brought in to operate the GIS for the planners.

Somers (1989) has written of her extensive experience in developing staff ability to use applications of desktop analysis tools. She recommends that current staff be given the opportunity to learn techniques and software. Analysts need time to practice with planning processes, and to share knowledge with others inside or outside of the organization, informally and through user groups.

The path which management takes with regard to developing the capacity of staff to master and use computer analysis tools like GIS will determine the success of the system. Staff with the interest and skills for doing computer analysis will either have to be developed, or hired. The managers of these employees will need to understand and support and reward the peculiar requirements of their work.

GIS appears to have many practical applications for school planning; but we really can't be sure how practical the applications are without investigating the investment in information resources and data management capacity necessary to implement these applications. The next chapter will detail these issues.
5

IMPLEMENTATION ISSUES

The core applications discussed in the previous chapter would be useful for school planners and administrators; but what sort of investment would be necessary to develop and maintain the necessary arrangements for applying desktop GIS? Thinking in terms of investments: what are the issues which should guide a wise, robust investment in information resources? And how should the manager consider building the necessary capacity of the staff for maintaining and using the system? This chapter will discuss the information resources and staff capabilities necessary for using GIS in terms of their value, cost, and risks.

5.1 RESEARCH FRAMEWORK

The general concepts described below will form the analytical framework for discussing the issues in developing information resources as investments. The general issues are discussed for each of the information resources which are necessary for the core GIS applications for school planning.

5.1.1 User Needs: Chapter 4 includes a discussion of the user-needs of the planners and administrators at Newton Schools with regard to GIS applications. Desktop-accessible databases have many purposes beyond a
single GIS application. Before a database is developed, the probable needs and uses of the database should be anticipated. A thorough investigation of needs assures that the investment in data will be leveraged with as many benefits as are possible, and will be safeguarded against an unexpected need to reconstruct, or retrofit, an expensive database application to accommodate some unforeseen need.

5.1.2 Development: The initial investment in information resources involves building, converting, or making arrangements to access computerized databases. Before starting from scratch, opportunities should be exhausted to salvage existing information resources or to use pre-existing electronic databases from other sources. Development of databases should always proceed with an eye on maintenance (see Section 5.1.4).

5.1.3 Versatility: A large cause for concern when speaking of investments in information resources and technology is obsolescence. The term versatility as used here denotes the opposite of obsolescence. As opposed to obsolescence, versatility is a matter of degree. The usefulness of an information resource is the primary return on an investment. Assuring versatility is a matter of design of databases and applications for using them. The familiarity of the users with the potential uses of the information resource is the key determinant of versatility.

In developing GIS databases for Newton Public Schools there is a danger that work may be wasted should the schools department later join the city in a unified GIS based on Arc/Info software. To ensure the continued usefulness of the applications and databases produced for a desktop GIS, careful attention must be paid to the database design and to making applications software-independent.

5.1.4 Maintenance: The most important part of the investment in information resources goes to maintenance and support (Thompson 1989). An investment in database development and applications will decay if updates are not made completely, accurately, and in a timely manner.
Assuring that data is maintained correctly is a critical element of protecting the investment.

There are several approaches for assuring that data is maintained. First, is to consider the possibility of maintenance before a data resource is built; there is little point in investing in databases if there is little chance that the data will be maintained. Second, the design of the database management application can help assure proper data maintenance. If the database is useful in departmental work, and the management application provides easy access and error checking, then it is likely that the investment in data will not be lost through lack of proper maintenance.

We will now look at how these issues relate to the information resource requirements for the core applications: 1.) the GIS Streets Database, 2.) the eligibility database (master streets database) 3.) The address/attribute files (e.g. the student database and the city census) and 4.) the transportation database.

5.2 THE GIS STREETS DATABASE

The GIS streets database is the key to all of the GIS applications for school planning. It provides the spatial framework for all of the address information and boundary layers which will be linked together using the GIS.

5.2.1 User Needs: A GIS streets database suitable for school planning applications will be useful for many other GIS applications throughout the city. Of particular interest is the likelihood that GIS applications involving address-matching will be used by the city census, by emergency dispatchers, and by the city planning department. Since the schools department is a branch of the Newton city government, development of a GIS street database should be coordinated with other city users. Murakami and Greenleaf (1992) have written a useful case study of the issues of coordinating GIS street database development and sharing the costs among users.
Coordination of users in the development of a GIS street database will ensure that a wide range of data can be integrated for planning applications. For example, building permit applications from the inspectional services department may provide useful information for school enrollment forecasting. If all city departments are using the same GIS street database the ability to integrate city census and city planning information into school planning decisions will be assured.

5.2.2 Development: Development of a GIS street database from scratch is a very expensive process. Fortunately, GIS software vendors are able to provide basic street databases for between $250 and $1000. These databases are derived from the U.S. Census department TIGER street map of all of urbanized areas in the United States. The TIGER files themselves can be copied free at many libraries; however the census product must be processed and converted to new formats for use in particular GIS packages.

None of the off-the-shelf GIS street databases will be sufficient for serious GIS applications without some development. There are two main categories of errors encountered in GIS street databases: spatial inaccuracies, and errors or omissions of the street name and address information. For the core school planning applications of desktop GIS, the accuracy of the name and address attributes of streets is most critical.

Errors in street-name spelling, errors in the address-range information, or missing pieces of streets in the GIS street database will prevent a complete matching of all of the student records. Incomplete matching of address-attribute records will bring error into many of the calculations and queries which are important to planning. A very good treatment of the problems with street databases is given by Hildebrand (1990).

To ensure that address matching is reliable the names and addresses in the street database needs to be checked. TIGER file accuracy varies from city to city. In Newton, trial runs of address matching yielded about a 90 percent chance that an address that was correct in the student database
would find a location. It is estimated that the corrections necessary to make any correctly spelled address locate via GIS address-matching would involve about two weeks of work for an experienced GIS user.

The spatial accuracy of the TIGER files also leaves a lot to be desired. None of the core applications described in Chapter 4 involve making spatial measurements of any kind; however, measurement of walking distances would be a useful application. Until a more spatially correct street database is available, the schools department should continue to measure walking distances to addresses using more accurate paper maps and field measurements. Development of a spatially accurate GIS street database is something which the schools department might defer to the city engineer or assessor.

5.2.3 Versatility: To frame the discussion of versatility of GIS street databases, it will be useful to discuss the reasons why a street database would become obsolete. Unless precautions are taken, street databases based on TIGER files can be expected to become obsolete when a more spatially accurate street database becomes available through some other city office, or when the next generation of TIGER is made available.

If the schools department invests in correcting a TIGER file for its applications, this investment should be protected by assuring that the corrections can be transferred to a new streets database without too much trouble. Street attribute information which is useful for school planners, such as identification of hazardous streets, bus-related street information, and address ranges can be linked with a street segment identifier such as the census department's featureID. This number will serve as a link between the newton schools-specific information concerning street segments and any new street database which is released by the census bureau or modified by the city (providing the city also retains this ID number). Good references for standards for protection and transfer of street attribute information are given in Cooke (1991).
5.2.4 Maintenance: In Newton, street information does not change very often; so the issue of maintenance of the street database may not seem that important. Yet, it would be useful for one department to be designated as the source and authority for changes in the city's GIS street database in order to maintain standards and currency among interdepartmental users.

There are two strategies guiding the decision of where this data should be maintained. The most obvious choice would be the office with primary responsibility for approving name changes, address changes and street alignments (assuming that this is one office). This would assure that the information originates at the most authoritative source.

The second strategy would be to give the responsibility to the user for whom correct street information is most important. This would probably be the emergency dispatcher. If that department does not use GIS, the schools may be the department with the greatest need. The issue of who maintains the master GIS street database is a topic to be decided by the GIS taskforce.

5.3 THE ELIGIBILITY DATABASE

If the core GIS applications are implemented, there will be a new method for updating the master streets database (see Section 4.2). The information for this document will be derived from the GIS streets database, and a set of GIS eligibility boundaries. The complete user needs for this information is given in Section 4.2.1.

5.3.1 Development: The addresses where eligibility boundaries divide streets and turn corners can be extracted from the existing master streets database. This process could be performed in a few hours by someone familiar with database management concepts. This file will define the critical corners of each boundary. Once the boundary-corner address file is created it will be address-matched in the GIS and used as a guide for creating the GIS eligibility boundary layer.
5.3.2 Versatility: The eligibility database and GIS application is robust with regard to changes in GIS software or changes in the GIS streets database because the critical information regarding eligibility boundaries is stored as addresses instead of actual spatial locations. As long as the address attribute information for streets is protected through the use of census ID numbers, the schools department investment in an eligibility database will be protected in the case of a wholesale replacement of the streets database or a change in the GIS software. The outlining of the eligibility boundaries would, however, have to be repeated in the event of a replacement of the GIS street database.

5.3.4 Maintenance: Maintenance of the eligibility database will be a matter of re-defining corners and adjusting the eligibility boundaries as needed. There is little danger of inadvertent corruption of this information between updates, which are rare. All work in experimenting with different eligibility boundaries should be done using copies of the master files. The master files should be kept in a read-only form on a file server in the ATC.

5.4 The City Census and the Student Database

The City of Newton has had a system of interdepartmental standards for street identification since the late seventies. These standards were created in order to assure that the city census was compatible with the school department's master streets database. The consistency of street-name spellings which results from these standards makes the linking of the city census and the student database GIS with an accurate GIS street database almost trouble-free. Other cities may not be as fortunate.

Many files containing addresses and attribute information are available in computer readable form throughout the city. These are often simply the transactional databases and mailing lists for the census, the schools, the assessors office, the building inspector, etc. Any of these resources can be very useful when address-matched in a GIS application.
5.4.1 User Needs: The user needs for these transactional databases are varied, but in order to use these resources in conjunction with GIS functions two important needs arise. The database needs to be available in computer-readable form, and the spellings and treatment of street-names needs to be consistent with those used in the GIS streets database.

5.4.2 Development: It will probably not be worthwhile to develop an address and attribute file of any size from scratch for the sole-purpose of using a GIS. But the potential for GIS applications may warrant the conversion of an existing database to computer readable form, or arrangements to apply standards to an existing computer database—especially if to do so would enhance the versatility and maintainability of these information resources for other administrative purposes.

5.4.1 Versatility: The advances in the use of computing in organizations have been built on the use of administrative data for strategic and analytical purposes. The use and combination of administrative address information resources through desktop GIS is an excellent example of this phenomena.

5.4.2 Maintenance: Strict quality control is required in order to maintain the links between address-attribute databases and GIS street databases. Quality control demands that standards for street address information be proposed, agreed on, documented, disbursed, and adhered to by each and every department whose data is necessary for an important GIS application.

The implementation of address information standards can be supported with automated spell-checking applications. Many database management software packages support custom spell checking dictionaries, and it is not difficult to adapt custom spell-checking programs to mainframe database management programs. Such a program would present a short list of streets to the data entry person once he or she has typed one or two letters of the street name; the user then could pick the complete spelling of the street from the list. City departments, if inspired to cooperate in building a
versatile city-wide information resource could share a common spell-checking application.

5.5 THE TRANSPORTATION DATABASE

The development and support of a transportation database, necessary for the bus transportation and planning application of GIS (see section 4.4) will be justifiable aside from its use with GIS.

5.5.1 User Needs: The responsibilities of the transportation coordinator include a great deal of information collection, analysis and reporting (see Section 4.4.2). In the current system, in which all of this information is updated manually (albeit on computer word-processing software), many items of information are repeated and updated in several different documents. For example, the location of a bus-stop is given on the bus schedule for each school serviced by the given bus, and in the driver's directions for the morning run and the afternoon run, which are different for each day of the week. If the location of the bus stop changes, as many as seven documents must be updated to reflect the change. A database management program with the ability to relate separate tables of information could provide for automatic updates of each report with a single change in a key table of bus-stop locations. The same database could export schedule information to a project-management software package for automatic creation and adjustment of graphic schedules.

5.5.2 Development: The development of the transportation database is underway. The process involves conversion of the 30 bus schedule documents from Microsoft Word to plain text files. To this basic database the stop sequences and arrival times from the morning and afternoon runs were transferred from the driver's directions. Later, the actual times and ridership information from the driver feedback reports can be added.

To gain the advantages of a relational database management system, in which a single bus-stop change will be universally updated in all of the schedules, the information will need to be normalized according to the...
relational database model (Date 1983). The result of normalization will be a set of related tables. The main table will have a record for each stop, indicating the associated bus-run, the morning and afternoon arrival times for each day of the week, and the address location of the stop. A second table would have a record for each bus indicating the runs for which that bus is responsible.

The spatial objects associated with the transportation database will be the stops, which will be address-matched using the address locations in the transportation database; and the routes, which will be lines connecting the stops. The creation of these line objects will involve manually connecting the stops in sequence.

5.5.3 Versatility: Any database management software capable of relating separate files can be used to maintain the transportation database. The software choice for maintaining the database should be guided by the ease of data maintenance, the ability to customize reports as needed and the ease with which data can be imported and exported to other applications. It is unlikely that any GIS package will be able to offer the full versatility in database management and report generation that a dedicated database management tool can provide.

Since the link between the transportation database and the GIS is through address and other attribute information (stop and route identifiers), the GIS software or the streets database could be replaced without much problem; however, the route-objects may need to be re-drawn.

5.5.4 Maintenance: The transportation database will be maintained both through the GIS application and in the database management application itself. This could be achieved through exporting the database from the database manager to the GIS and project management software for the graphical updating and query, and exporting it back to the database management software for making reports such as the driver directions and schedules.
Maintenance can be facilitated by the use of a database management tool which allows the creation of automated procedures for importing, exporting and manipulating particular arrangements of data.

5.6 CONCLUSION

The information resources required for developing GIS applications for school planning will be useful for many other applications. The multiple uses of data, the expense of data development, and the fast changing data management environment require that data development be carefully planned.

Like computerized analysis, the planning, development and support of electronic databases using desktop computers is an area which is only beginning to develop in Newton Public Schools. The staff development and support for maintenance of electronic databases is an important part of adopting GIS for school planning.

5.6.1 Planned Coordination: The schools should use its participation in the Newton GIS task force to initiate a program to develop a standard GIS street database and a corresponding standard treatment of addresses. A high level mandate may be necessary for departments without an immediate need for coordination to participate. If the schools department has to take the lead in developing a streets database the possibility of sharing the information with other users, or incorporating another GIS street database should be provided for.

5.6.2 Phased Resource and Application Development: Because the core applications build on eachother's information resources, a phased development scheme would enhance the spin-off effects of one application on another. Since Newton has just completed a redistricting effort, the most justifiable GIS application is the update of the master streets database; a major re-planning of the transportation system will be the next major application og GIS.
A corrected GIS streets database is the primary information resource necessary for developing the eligibility database management application (see Section 4.2). Development of this application would produce the boundary databases which are important for the district planning and the transportation planning applications.

The redistricting application requires only the eligibility boundaries produced by the eligibility database updating application and address matchable files from the student database and the city census. These files could be produced by the ATC, and made available on disk, or through the education center network.

The transportation planning application builds on the boundaries and address information which are required for the two applications discussed above. The only additional requirement is for the transportation database.

5.6.2 Developing Database Management Capacity: It has been taken as a given in the preceding discussion that departmental database management applications such as the transportation database would be in use, that computer files will be extracted from existing administrative databases and shared among departments, and that departmental managers are interested in discussing standards. These conditions require a degree of understanding of database management at different levels of the organization which may not currently exist. This may entail an organization-wide education strategy (see Azad 1987).

The director of the ATC is beginning to support this activity through classes in database management and development of customizable software for specific office applications. This coordinated effort will assist particular offices in managing their resources, but will also help the ATC in coordinating the orderly development of the organization's electronic information resources. A critical role of this position would be to maximize the potential of the school system's information resources, and to design and supervise maintenance procedures.
The director of the ATC has proposed that a staff position be created for a coordinator of desktop computing applications. This staff member would evaluate needs, plan and develop applications and provide training and support to users. This position may also be a logical place to put a person who is capable of coordinating the development of GIS applications and communicating with the Newton GIS taskforce.
Applications of desktop GIS can improve the efficiency and the effectiveness of planners, and service providers, school departments and, quite likely, other municipal departments. Integration of GIS with a municipal department's procedures and information resources presents a challenge to department managers; a challenge to develop staff skills, information resources, and coordination with other departments. These challenges will be the much same regardless of the software: whether it is a large-scale municipal GIS, a completely packaged turn-key consultant system, or a generic, off-the shelf piece of software. Reviewing the issues uncovered in the case study of Newton Schools allows us to evaluate the three alternative pathways to developing departmental GIS capability.

Sections 6.2 and 6.3 of this chapter will review the issues of resources, and staff development and inter departmental coordination which have been found to be important in school department GIS applications. Using this background, the three alternative pathways of GIS development, large-scale, consultants single-purpose packages, and generic desktop GIS, will be reconsidered.
6.1 DEVELOPMENT OF DEPARTMENTAL RESOURCES

The promise of desktop GIS as a tool to help planners integrate electronic data from various sources poses a challenge to department managers. The ability to use analytical tools such as desktop GIS is a step in an organization's development which builds on the capacity of staff to manage electronic information, the establishment of geographic and administrative databases and the capability of planners to use computer-based analysis. The extent to which these developments can be hurried varies in relation to the commitment of upper levels of management to understand and foster these development needs.

6.1.1 Electronic Information Resources Management: Managing information is a key function in service organizations such as schools. Mainframe computing has been applied to the heaviest of work in information management since the late sixties. Tools have been developed to use the information resources on the mainframe to do analysis. Until recently, these tools have been available only to computer specialists, and the ability of planners to answer questions which had not been anticipated by the specialists depends on understanding the capabilities of computing, a knowledge of the information resources, and access to computing experts.

What has changed now is that computing tools are now much more accessible. Generic tools for managing and analyzing data have become much easier to use, What remains before the potential of desktop computing is realized is that managers and staff learn how these tools can be used.

At the department level, many information resources are created, accessed and updated using manual methods. These information resources, essential to operations, are difficult to access and maintain. The wide availability of desktop computers offers an opportunity to manage departmental information resources electronically. The capability to manage data electronically permits information to be developed, accessed, and printed more flexibly, accurately and efficiently. Development of an organization's
departmental information resources also permits information to be linked between departments and with the central information base. The combination of the overall information resources is much greater than the sum of the individual parts.

6.1.2 Staff Development: Development of the capacity of staff to design and manage electronic databases is a project which requires organized coordination, and support. Staff cannot be expected to learn or practice these skills on their own time. The development of versatile information resources will not happen if left to chance. The management of municipal governments and of individual departments should set as a high priority the support and coordination of electronic information resources development including database management training, and development and support of customized database management applications.

Finding, and keeping staff members who are interested in developing data management and analysis tools is one of the biggest challenges in developing and using electronic information resources. Investing in the learning and knowledge of the staff will be the challenge. Providing an environment where staff members can practice, share information, and be rewarded for innovation will have to be priorities.

6.2 Coordinated Geographic Information Resources Development

Electronic geographic information resources are a means of integrating various information resources through spatial relationships. The cost of these electronic map-bases has declined drastically due to the involvement of the federal government in database creation. The cost also declines as numbers of potential users of GIS in an area increases. Cooperative development of electronic maps by city departments also has the benefit of an assured linkability of municipal information through geographic relationships.

Coordination among municipal departments in the development of electronic map bases will not happen if left to chance. In order to fully exploit
the benefits of using spatial relationships to integrate planning information, and to avoid the cost of unilateral development and maintenance of the data, each interested department manager must learn about the important issues and actively participate in the development of standards, resources and, arrangements for maintaining and distributing the resource.

6.2.1 Defined Responsibilities and Standards: If the responsibility for updating certain key geographic databases such as streets, or the city census is defined for a few central departments, the coordination of GIS activity will not require a wide-area network or standard software. Coordinating the street information resources as early as possible, and giving departments address-matching capability, will provide a framework and a reason for coordinating the address references used by various departments. This coordination will be the groundwork for integration of information resources and should permit better planning and responsiveness throughout the city government.

6.2.2 Software Independent Databases and Applications: For departments developing independent capacity to use GIS, the primary investment is in staff skills and information resources. Desktop GIS software should be considered expendable. In the quickly changing world of GIS, many software products will become obsolete or out-classed by competitors in a short time. Eventual standardization across municipal departments may also call for software changes. Investments in skills, data, and applications will be safe in the event of a software change if proper precautions are taken (see Section 5.1).

Software should be capable of transferring geographic data (the information necessary to produce a map) through a recognized interchange format. Any claims to data transferability made by software vendors should be verified carefully; this is something which seems to be easier to say than to do.

Investments in GIS street data development should be protected through the use of standard identification numbers for each street segment.
(the piece of street between every pair of intersections). If a standard set of identifiers, such as the census feature-IDs are used by the city on its master GIS street database, this will ensure that any special information maintained by departments (e.g. school-bus driveability) can be transferred to a new street database with ease. The use of census ID numbers will make the use of the street database with the current and future census products possible.

Applications can be protected against changes in software or base-maps by careful attention to the spatial referencing which is used by the application. If an application such as the eligibility database (see Section 4.2.3) uses street address as its primary spatial reference then the same application will be easily convertible to a new GIS software platform or street database. The more complex the application, the more software-bound it is likely to be.

6.3 Capacity of Planners to Use Computer-Based Analysis

The promise of desktop data management and the ability to link data resources through geographic information systems is that of planners and decisionmakers being able to access and combine the information resources of their department and other agencies directly without depending on anticipated, pre-programmed solutions or long turnaround times which were necessary in mainframe-dependent organizations.

The capacity to use analytical tools such as desktop GIS demands a knowledge of the information resources which are available, an ability to work with electronic information. Tasks of this kind require more practice and inter-departmental communication than the traditional way of doing analysis. Accomodating these new work-styles may take some adjustment on the part of managers.

When GIS is used to its potential, important analytic and administrative work will be done at the computer. Of course, the person doing this work will be the planner and the administrator. The development of a management, clerical and analytical staff that has the expertise to use
and maintain GIS applications will be the biggest challenge faced by municipal governments. Achieving this goal requires an understanding and commitment of the highest levels of management.

6.4 THE THREE ALTERNATIVES REVISITED

Now that the issues involved in building a departmental GIS from the ground up have been detailed, how might a departmental manager weigh the advantages of large-scale municipal GIS, consultant’s “packaged solution” GIS, or the generic desktop GIS alternative?

6.4.1 Large Scale Municipal GIS: The idea that the city’s centralized GIS program will “take in” a department such as the schools is a false hope. A better way to view the large-scale municipal GIS model is as a network for sharing information resources. The central GIS staff may provide coordination, software and application support; but the responsibility for managing departmental information resources, and analytical capacity will remain in each department.

The department-head’s approach to this model should be to get a knowledgeable staff-member on the GIS taskforce as soon as possible. In waiting, opportunities may be lost for having important input to the city's standard setting and data-building policies. While the municipal GIS is developing, each department should be developing its own electronic information resources and the capacity to use them. No participation in a municipal GIS will be possible until after these skills and resources are developed.

6.4.2 Consultant Packaged GIS Solutions: Hiring a consulting firm to develop and maintain a GIS system seems to have advantages, but these advantages are only temporary. A consultant’s packaged GIS solution offers the manager an opportunity to avoid dealing with all of the organizational issues of developing resources, staff, and coordinated, versatile applications. The manager can avoid these issues simply by signing a check. For the money, the department will get a stand-alone, single purpose package of data
and applications for some need (e.g. school planning). This investment may pay off if a school bus is eliminated from the transportation system, but a packaged solution may not be the best value for the department or the city.

The main issue to consider in this alternative is versatility. Will the information resources and applications which are developed be versatile and tolerant of changes in software? Will the consultant be concerned with the on-going arrangements to share GIS street data maintenance with appropriate municipal partners? Will the training provided by the consultants be enough to assure that the staff and planners are capable of managing and adapting the information resources and applications if the consultant, for whatever reason, fails to support the product?

As discussed in Chapter 5, protecting the versatility of information resources and applications depends on being as independent as possible with regard to software; the same concept holds for consultant’s services. The department managers should clearly understand the opportunities, and risks at stake in devising strategies and making investments. It may be useful to use consultants for some of the data development, or application design, but in matters of developing the department’s and the city’s information resources, the managers of the enterprise should have a clear understanding of the opportunities and the issues.

6.4.3 Generic Desktop GIS: The development of desktop GIS applications for a municipal department such as Newton Schools poses a challenge to the department’s managers. The challenge is not posed by the advent of this one particular piece of software however. A large part of the challenge is developing an organization which is capable of maintaining and using electronic databases on the desktop. This is not an easy task, but the difficulty should not be ascribed to GIS particularly.

The particular challenges posed by desktop GIS are planning and coordinating geographic data development, developing simple applications, and training staff in the use of tools. If the information resources
management challenge is managed wisely then the desktop GIS implementation challenge will be relatively simple.

The recent availability of inexpensive, easy to use desktop GIS software and street data presents the possibility that a new model for municipal GIS development may evolve. While intensive GIS databuilding tasks are occupying the city's GIS experts at the assessing and engineering departments, municipal departments interested in GIS should be developing their address and attribute databases, simple boundary layers and applications.

By beginning their own applications, the planners and staff in these departments will develop skills and information resources necessary to coordinate with a networked municipal GIS when it comes on line. In time, departmental desktop GIS, which is presently a single-user tool, may become a department's link with the central GIS enterprise. In the meantime centrally maintained data such as GIS streets databases can be transferred on disks or tape.

If departments such as Newton Public Schools approach this challenge carefully, they will provide a model and a head-start for other municipal departments. A city-wide effort will enable each department to benefit from shared information and coordinated planning. If the city-wide coordinated effort takes years to realize, the investment in resources and capabilities can be applied to improving the responsiveness and efficiency of services using in-house skills, resources and software.
BIBLIOGRAPHY


SCHOOL TRANSPORTATION PLANNING in NEWTON

POLICY

STATE GENERAL LAWS

LOCAL SCHOOL COMMITTEE

ELIGIBILITY REQUIREMENTS
- Distance/Grade
- Facilities (private)
- Programs (bilingual)

TECHNICAL REQUIREMENTS
- Walking distance to stops
- Maximum ride time
- Grade mixture in vehicles

ADDITIONAL LOCAL POLICIES
- Siting decisions
- Districting
- Technical requirements

ADMINISTRATION

POLICY ASSESSMENT
- Physical definition of eligibility areas
- Assignment of eligibility to students

TRANSPORTATION COORDINATOR

STUDENT ASSIGNMENT
- Siting stops, defining service areas
- Assigning students to stops

ROUTE PLANNING
- Grouping of stops
- Establishing stop sequences

IMPLEMENTATION

SCHOOL BUS CONTRACTOR

TRANSPORTING STUDENTS
- Provision of buses
- Employment of drivers
- Carrying out routes and tours

DEVELOPMENT OF BUS TOURS
- Assigning time windows to routes
- Assigning routes to busses

PROVIDING INFORMATION
- Instructions for bus contractor
- Feedback to school committee

PROVIDING INFORMATION
- Ridership
- Actual arrival times

Issues in the Adoption of Desktop GIS for Schools Planning

---

Paul B. Cote, MIT Computer Resources Laboratory