Multi-Level GIS-Based Data Management Model for Building Maintenance and Repair Data

by

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ABSTRACT

With the increasing cost of new construction projects, keeping the built facilities at acceptable levels of functionality has become a vital and challenging task. This is particularly so for non-residential buildings, such as schools, which are important infrastructure assets that require frequent maintenance and repair of their many components and sub-components. Maintenance and repair jobs, however, involve huge sets of data which contain useful interrelated information about costs, resources, conditions, and productivity. To support decision making at different management levels with respect to the utilization of resources requires the managing, analyzing, and visualizing of these huge amount of data.

This thesis presents a simple and inexpensive approach to managing, reporting, and facilitating the visualization of maintenance and repair data for school buildings. The proposed model conveniently integrates widely used spreadsheet software – MS Excel – and Geographic Information System (GIS) software – MS MapPoint. The spreadsheet's simple and powerful capability of managing data is exploited to design a data warehouse that can facilitate reporting and visualization. The Visual Basic for Applications (VBA) programming language was used to facilitate the integration between the two software systems and to automate the generation of a variety of reports and maps that can show analysis trends, reveal hidden relationships, and support decision making for different management levels. A real-life case study involving two years of maintenance data for 93 schools at the Toronto District School Board (TDSB) is used in this thesis to illustrate the development of the model and to demonstrate its simplicity and efficiency. The use of the model as part of an integrated framework for building asset management is also highlighted.

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Chapter 1

Introduction

1.1 Background

Infrastructure surrounds people and contributes to their daily living. It touches almost all aspects of life, from transportation and water/ sewer systems to health care facilities and educational buildings. Because it plays a significant role in supplying essential services both to the public and to business, the signs of its deterioration worry a broad sector of the population. While natural disasters have certainly contributed to some infrastructure failures, many others have occurred because of lack of repair and maintenance, inaccurate condition assessments, or improper spending: in short, because of inadequate management.

The infrastructure report cards published by the American Society of Civil Engineers (ASCE) from 1998 to 2005 show limited improvements in all infrastructure sectors, despite significant spending levels. The 2005 report card gave failing grades to many infrastructure systems and identified the need for $1.6 trillion (US) to bring the United States (US) assets to an acceptable condition (ASCE, 2005a). In Canada, for instance, the environmental, social, and transportation infrastructure systems alone require an estimated $10 billion US annually for ten years (Federation of Canadian Municipalities, 1999). Despite the enormous need for repairs, the Infrastructure Canada Program allocated only $2 billion US for 2000 for all infrastructure sectors (Federation of Canadian Municipalities, 2001). In general, all infrastructure sectors experience large short fall in their budgets caused by the urgent need for rehabilitation and repair. For example, the investment shortfall for municipal and regional roads is reported to be $9 billion (National Research Council of Canada, 1999), and the shortfall in public transit is $8 billion or more (Canadian Urban Transit Association, 1999). With the expenditures for the non-residential buildings in Canada and the United States being the largest among all infrastructure sectors, at 37% and 63% respectively (Figures 1.1a and 1.1b)(Statistics Canada, 1997; and U.S. Census Bureau, 1999), this area is expected to suffer the largest shortfall in expenditures for rehabilitation and repair.

The majority of non-residential buildings are schools and educational facilities. In the ASCE report card of 2003, the school sector was given the worst grade (D^{-}) with no improvement shown since 2001 (ASCE, 2005b). The report card also showed that 59,400 schools, about 75% of all schools in the United States, require repairs, renovations, or modernization in order to have their condition classified acceptable. In addition, about $127 billion US is required in order to restore school facilities to a good condition (U.S. Department of Education, 1999). The National Education Association’s estimate is even higher: more than $268 billion US (National Education Association, 2000).

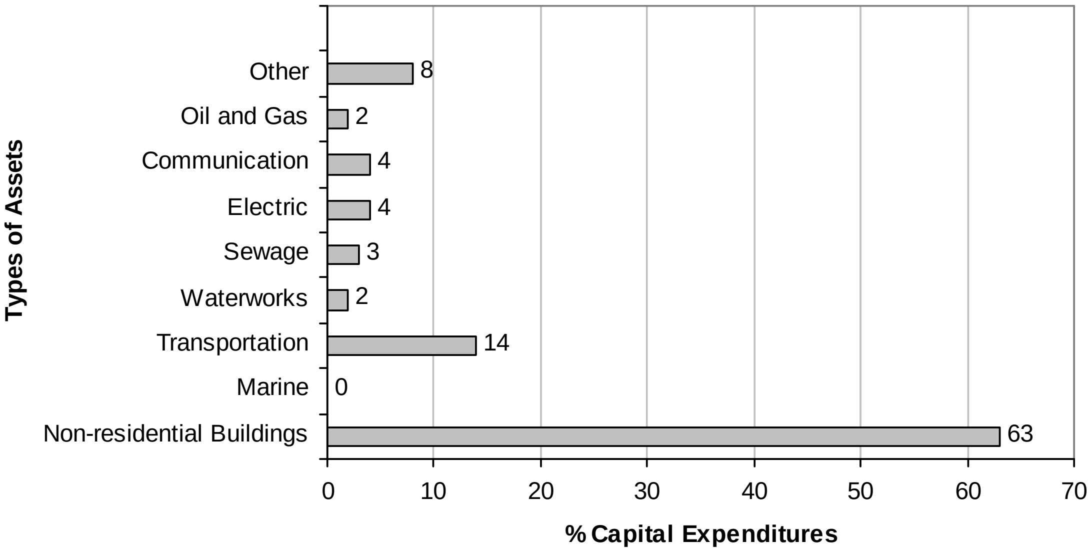


Figure 1.1a: Yearly Expenditures by Types of Assets in the USA (U.S. Census Bureau, 1999)

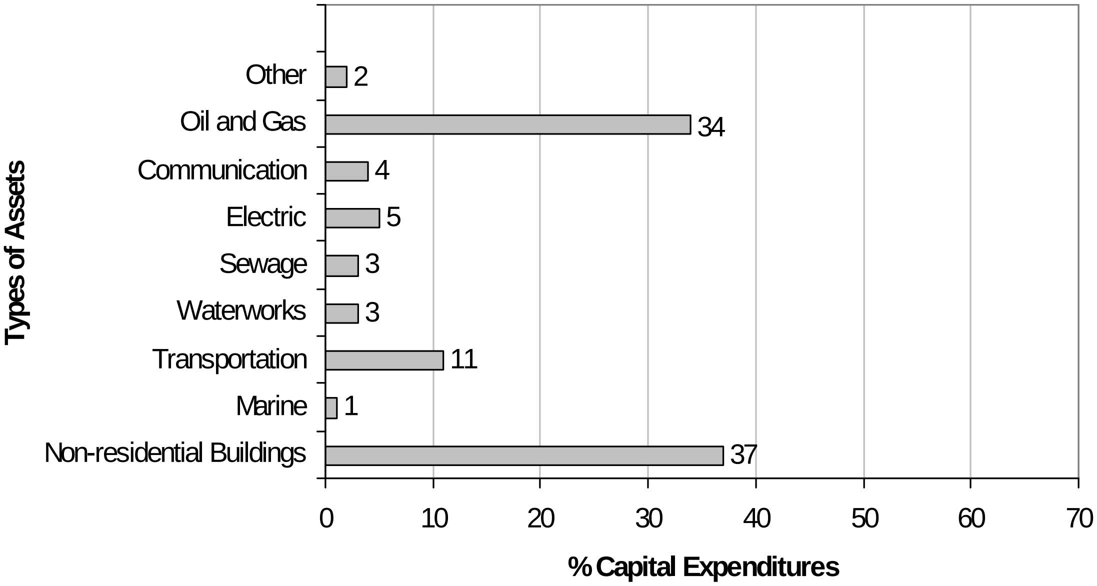


Figure 1.1b: Yearly Expenditures by Types of Assets in Canada (Statistics Canada, 1997)

As a result of these huge shortfalls, hundreds of billions of dollars in maintenance are backlogged in North America (Vanier, 2001a). As an example, Figure 1.2 presents an age profile of the educational buildings of the Toronto District School Board (TDSB) along with their expected renewal needs as compared to the funding level (Physical Planning Technologies Inc., 2003). To respond to the large maintenance backlog, the TDSB spends a significant amount of money annually on rehabilitation for its large number of school buildings.

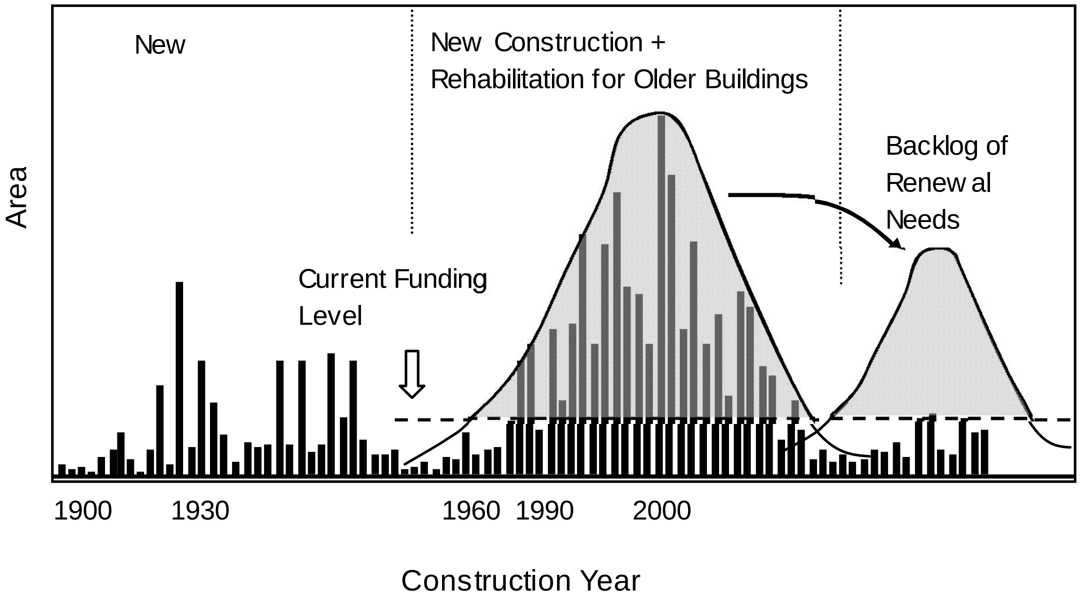


Figure 1.2: Construction-Age Profile with Expected Backlog

(Physical Planning Technologies Inc., 2003)

Because the total value of civil infrastructure in North America is estimated to be $20 trillion of (Attalla et al., 2003), infrastructure assets need to be monitored and maintained in order to keep their functionality at satisfactory levels. In recent years, the largest portion of all construction work has been shifting from new projects to reconstruction and rehabilitation. Lee (1996), for example, reported that up to 50% of the total construction budget in the United States for that year was spent on a form of renovation, remodeling, reutilization, or rehabilitation. The Board on Infrastructure and the Constructed Environment (BICE)(1999) stated the following:

> The United States spends an enormous amount of money annually to replace or repair deteriorated equipment, machines, and other components of the infrastructure. In the next several decades, a significant percentage of the country's transportation, communications, environmental, and power system infrastructure, as well as public buildings and facilities, will have to be renewed or replaced.

In Canada, the value of built assets is increasing at the rate of approximately $100 billion/year (Vanier, 2001b) (Figure 1.3). This growth has resulted in the total stock of buildings and constructed infrastructure being valued at an estimated $2.94 trillion, as shown in Figure 1.4 (Vanier, 2001b). These values are significant and frightening. However, the magnitude of these numbers does establish the extent of the asset management challenge: the operation, maintenance, repair, and eventual renewal of this built environment represents a major, and rapidly growing, cost to Canada (Vanier, 2001b).

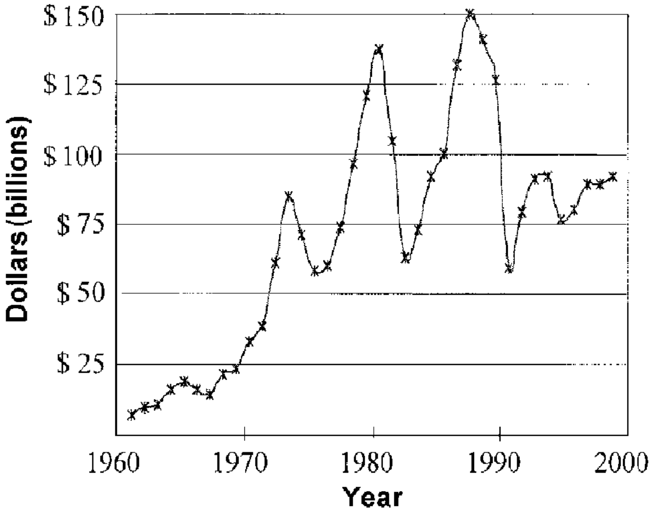


Figure 1.3: New Assets in Canada (in Billions of Dollars) (Vanier, 2001b)

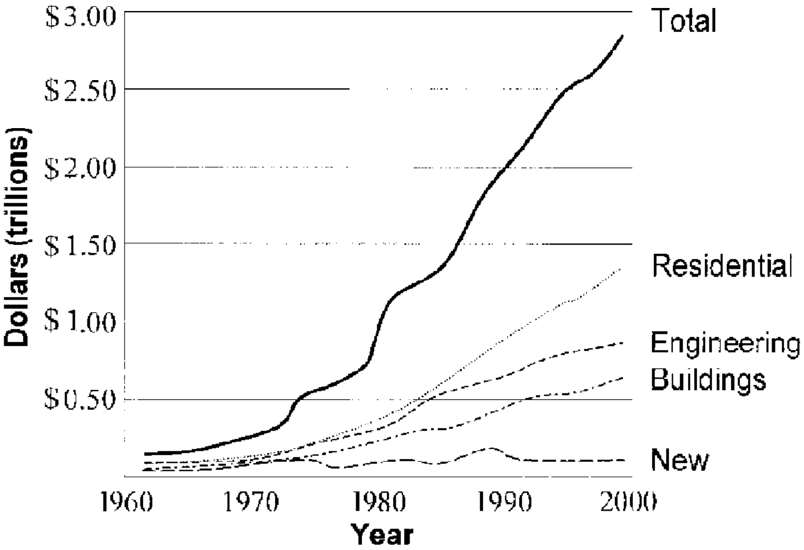


Figure 1.4: Total Assets in Canada (in Trillions of Dollars) (Vanier, 2001b)

In view of limited budgets, maintenance and repair decisions about constructed facilities such as schools are considered difficult and challenging by many owner organizations like municipal and provincial governments (Attalla et al., 2003). Non-residential buildings, such as schools, are complex facilities that are comprised of several components, such as the structure, services, systems, and internal and external finishing, that together provide the desired function. However, these components have varying service lives and are not entirely protected from deterioration due to usage, natural effects, and climatic conditions. Typically, the maintenance and repair of these components produce huge scattered sets of data that are typically neither organized nor rendered visualizable properly during the decision-making process, which may lead to ineffective decisions and conflict among parties and activities.

1.2 Research Motivation

This research on the use of visualization tools to support asset management decisions has been motivated by two main aspects: the potential benefits of visualization and the lack of visualization-based decision support tools.

1.2.1 Potential Benefits of Visualization

In general, extracting meaningful information from the very large sets of data associated with any maintenance schedule is the greatest challenge for the managers of the project when they are making decisions (Korde et al., 2005). The $100 billion increase in built assets every year (Vanier, 2001b) is also accompanied by an increase in this type of data. Because of their ability to deal with these large amounts of data, computers are increasingly in demand to assist with the challenges. Therefore, the industry has lately seen the use of a number of computer tools and techniques that can enhance communication, documentation, and coordination among all parties in a project. One group of these tools can assist with the difficulty managers often face in organizing, understanding, and comparing the data, that is, visualizing the relationships. These tools and techniques for analyzing and facilitating the visualization of data have proven to be beneficial, especially for the following tasks:

- Optimize and justify the conscious decisions made by construction managers to prevent unsuccessful projects (Russel and Udaipurwala, 2002).
- Provide valuable insights for all parties in a project to keep them on the same page (Korde et al., 2005).
- Link data from scattered sources and provide a comparison of textual and graphical reports (Vanier, 2004).
- Extract significant information, features, and results quickly and easily (Korde et al., 2005).
- Support further decision making, such as resource allocation and utilization to achieve optimum productivity and continuity.
- Improve quality and safety record.

Computer-based tools that can facilitate visualization have become promising and can contribute greatly to the sustainability of operation and safety of an asset.

1.2.2 Lack of Visualization-Based Data Management Tools

The large amount of infrastructure maintenance and repair data is usually available in inconsistent formats and is often related to multiple assets that are scattered throughout a geographic area. As a result, the need for a data management tool that can visually represent available data in a clear and easy-to-understand way becomes vital for comparative analysis, trend analysis, and decision making. In this way, data visualization can help improve the sustainability of operation and safety of the assets.

In general, however, there is a serious lack of standards, guidelines, and visualization-based computer software to assist managers with their decisions related to repair-fund allocation and the selection of cost-effective repair strategies (Coullahan and Siegfried, 1996; and Earl, 1997). The kinds of visualization-based tools that are lacking include the following:

- Tools that support the condition assessment process, particularly for old assets that lack historical information (approximately 30% of the 642 school buildings in Toronto are at least 50 years old (Figure 1.5) (Elhakeem, 2005).

- Tools for easily expressing asset deterioration patterns and the impact of repair strategies.
- Tools that provide a visual comparison of both network-level and asset-level needs.
- Tools that summarize the large amounts of data related to asset priority, repair needs, yearly expenditures, and yearly backlogs at different decision-making levels, such as geographical locations/districts/zones.

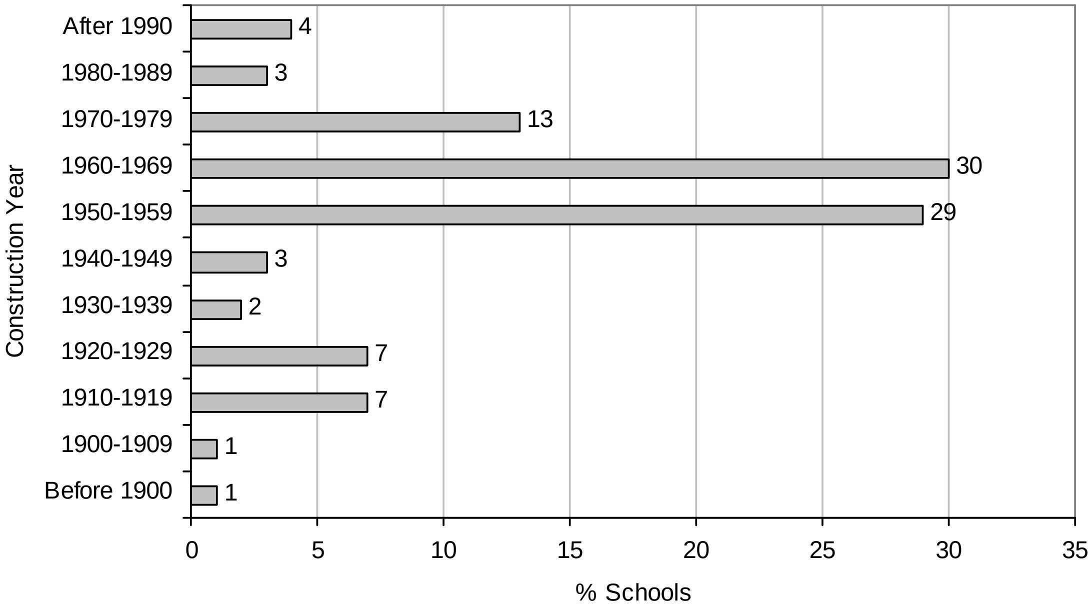


Figure 1.5: Age Distribution of Toronto Schools (Elhakeem, 2005)

1.3 Research Objectives and Scope

The goal of this research is to support maintenance and repair decisions for educational buildings and to develop a framework for visualizing the huge sets of geographically scattered data generated during maintenance and repair jobs.

The research examines the visualization needs of the infrastructure maintenance process and develops an effective data management tool for storing, analyzing, and visualizing large sets of building maintenance data to support various decision-making levels. The proposed tool provides helpful insights to those who are involved in scheduling, monitoring, and performing maintenance and repair jobs. The research has the following detailed objectives:

- Analyze existing visualization and data analysis tools available in the industry to determine which are appropriate. Features such as easy-of-use, flexibility, and cost are important factors.
- Collect real-life data from the Toronto District School Board (TDSB) regarding the maintenance and repair of a number of school buildings.
- Analyze the collected data and define the types of textual and graphical reports that are essential for various levels of decision making with respect to building maintenance and repair.
- Develop a visualization-based data management model that utilizes Geographic Information Systems (GIS) technology to accommodate multiple geographically scattered assets. The model provides a pre-designed template of the textual and graphical reports that are useful for decision making for building maintenance and repair.
- Examine the capabilities and the usefulness of the developed model based on input from decision makers at the TDSB.

1.4 Research Methodology

To achieve the objectives of this research, the following steps were carried out:

- Review the early efforts and current developments that relate to visualization and data analysis in the construction industry in order to determine the application suitable for the research.
- Identify the nature of the information used at each stage in building maintenance and repair decisions.
- Develop a comprehensive data management model that adopts spreadsheets and GIS technology to store, analyze, and facilitate visualization of the required data based on flexible user-selected criteria. The integration between the spreadsheets and GIS technology makes the developed model flexible and easy-to-use for the non-technical personnel involved in the asset maintenance and repair process.
- Provide the users with clear and easy-to-understand templates for reports, as well as easily readable GIS-based representations that are appropriate for different levels of decision making.

1.5 Thesis Organization

Chapter 2 reviews the literature review about available management research as it relates to infrastructure data. It also presents a review of the most recent efforts with respect to visualization technologies appropriate for infrastructure asset management.

Chapter 3 presents the process used to collect a large sample of infrastructure maintenance data as well as the preliminary analysis of the data. Data management and reporting needs are also discussed in this chapter.

Chapter 4 describes the development and working process of the proposed Multi-Level GIS-Based Data Management Model for managing, reporting, and visualizing maintenance and repair data for educational buildings.

Chapter 5 explains the implementation of the proposed model in a real-life case study of maintenance data. Components of the model and samples of the reports generated are also discussed. The chapter also presents the benefits of the model to identify new/hidden information in the large amount of available data.

Chapter 6 provides conclusions and recommendations for the extensions of the current research.

Chapter 2

Literature Review

2.1 Introduction

This chapter provides a brief overview of the infrastructure asset management and information/knowledge management practices that are important for managing large infrastructure data. In addition, this chapter discusses visualization technologies, especially those related to the construction industry, such as 4D-CAD and Virtual Reality. Also examined is the literature that deals with technologies that facilitate decision making for scattered infrastructure facilities: Geographic Information Systems (GIS).

2.2 Infrastructure Asset and Maintenance Management

Infrastructure has recently been attracting attention due to its deteriorating condition and the need for large investments to keep it safe and operational. At the same time, the goal is to keep costs as low as possible. The business processes that deal with these issues are called asset management and maintenance management. These terms are often used interchangeably but are really very different. Asset management is directed at reducing the overall cost of asset ownership, and maintenance management is focused on reducing maintenance cost while extending the useful life of the asset (Mckibben and Davis, 2002). An effective asset management system must include an effective maintenance management system. Asset management is a structured program that optimizes the life-cycle value of physical assets by reducing the cost of ownership, while providing the required level of service (Harlow, 2000). The objective of an asset management system is to minimize the long-term cost of owning, operating, maintaining, and replacing the asset while ensuring the reliable and uninterrupted delivery of quality service (Harlow, 2000). The major functions of an effective asset management system are summarized below (Mckibben and Davis, 2002):

- Effective asset design
- Effective maintenance management
- Effective asset rehabilitation or refurbishment and replacements
- Effective asset condition monitoring
- Effective financial planning

Asset management is, in fact, an engineering and planning process that requires substantial information to be collected from many different parts of the utility. This information must be maintained for many years in order to identify long-term trends. Asset management engineers and planners use this information to plan and schedule asset maintenance, rehabilitation, and replacement activities (Mckibben and Davis, 2002). Effective asset management also uses substantial information to support asset management decisions. The development of the required skills and information to support effective asset management is a long - term Endeavour requiring careful planning and implementation (Mckibben and Davis, 2002). Effective asset management requires information from many disparate sources.

Maintenance management is an organized process for producing reliable capacity from the utility's facilities (Palmer, 1999) at the lowest possible cost. Maintenance management is the process and procedures that are directed at keeping the assets working properly and extending their useful life. Maintenance management means more than efficiently providing asset maintenance; it should be a process that prevents unnecessary maintenance (Palmer, 1999) by providing the needed maintenance at the time it is needed. Effective maintenance typically has six major steps (Campbell and Reyes -Picknell, 2002):

- Identify the need for maintenance by visual inspection or evaluation of asset performance data.

- Plan the maintenance activity to make sure that all the needed information and resources are available and that proper documentation is prepared.
- Schedule the maintenance activities needed and identify the maintenance personnel who will be assigned the maintenance work. The work must be prioritized to ensure that the most critical work is completed first.
- Assign the crews and resources needed for the maintenance activity.
- Execute or complete the maintenance activity.
- Evaluate maintenance activities by ensuring that the proper documentation is prepared.

In the utility maintenance area, effective maintenance management does not mean simply installing, for example, a Computerized Maintenance Management Systems (CMMS) computer program. CMMS software is just a tool to help a utility provide effective maintenance by making important information available for the maintenance management decision process. The final decision still rests with the managers.

2.3 Information/Knowledge Management

In all functions, from inspection to maintenance, the infrastructure domain relies heavily on information, so it is important to review available tools and technologies that can support the efficient management of related information and knowledge. Information management and knowledge management are different. Information management is generally viewed as "using technology (e.g., computers) and techniques (e.g., information mapping) effectively and efficiently to manage information resources from internal and external sources for meaningful dialogue and understanding to enhance pro-active decision making and problem solving" (Rowley, 1998). According to (Faculty of Information Studies, 2007), information management is characterized as a cycle of five related activities which could be listed as follows:

- identification of information needs
- acquisition and creation of information
- organization and storage of information
- information dissemination
- information use

Collecting and managing information from several sources and distributing it to different users efficiently plays a major role in achieving systematic projects and reducing costs and uncertainty, and leads to more reliable decisions (Faculty of Information Studies, 2007), These features are extremely important in the case of infrastructure, where information/knowledge management play significant roles in decision making.

In the construction industry, information management software systems have been used to track construction processes in scheduling (e.g., Microsoft Project), cost control (e.g., spreadsheets), design (e.g., AutoCAD), and communication (e.g., NetMeeting) (Pan and Anumba, 2005). Furthermore, Geographic Information Systems (GIS) are used as information management tool to store, edit, manage, and disseminate information to the parties involved in a project in order to analyze spatially referenced data and to facilitate the decision-making process.

Knowledge management, on the other hand, comprises a range of practices or activities employed by the organization in order to identify, create, represent, and distribute knowledge for re-use or future referencing, awareness, and further learning (Wikipedia, 2007). Knowledge management actually pertains to the management of information within the organization. The objectives and activities of a knowledge management program are thus often tied to the organization's goals and vision and are normally directed toward the achievement of specific outcomes such as shared information, enhanced employee performance, increased competitive advantage, and improved innovation.

These goals are different from information systems and information visualization and management systems because knowledge management programs are directed at managing the procedures and operations for creating and identifying information as well as accumulating, consolidating, and applying it in the organization. This information is typically related to the intellectual and human resource capital; organizational practices, operations, and policies; and technologies such as databases, corporate networks, and content and document management (Systems Thinking, 2007). Thus, knowledge management may be facilitated through e-learning, web conferencing, collaborative software and webpages, e-mails, etc. These methods are basically the means by which the extent of inquiry available to the employees may be expanded. The applications of knowledge management include a wide range and variety of activities, such as on-the-job peer discussions, formal apprenticeship and training, and corporate libraries. With regard to computer-based systems, knowledge management may extend to technological innovations such as knowledge databases, expert systems, and other related repositories (Sveiby, 1996).

2.3.1 Data Mining and Warehousing

Because the data related to infrastructure is huge in size and scattered in nature, new tools for data mining and warehousing may prove beneficial. Moreover, the enormous amount of data stored in files, databases, and other repositories, has led to the development of powerful methods of analysis and perhaps interpretation of such data and for the extraction of relevant knowledge that could help in decision making (Osmar, 1999).

Data mining derives its name from the similarities between searching for valuable information in a large database and mining rocks for a vein of valuable ore. Both involve either sifting through a large amount of material or ingeniously probing the material to pinpoint exactly where the values reside. Other similar terms referring to data mining are data dredging, knowledge extraction, and pattern discovery (Osmar, 1999). Data mining involves the use of sophisticated data analysis tools to discover previously unknown valid patterns and relationships in large data sets. These tools can include statistical models; mathematical algorithms; and machine-learning algorithms that improve their performance automatically through experience, such as neural networks or decision trees. Consequently, data mining consists of more than collecting and managing data; it also includes analysis and prediction (Seifert, 2007). Data mining can be performed on data represented in quantitative, textual, or multimedia forms. Data mining applications can use a variety of parameters to examine the data including the following (Seifert, 2007):

- Association: patterns where one event is connected to another event, such as purchasing a pen and purchasing paper.
- Sequence or path analysis: patterns where one event leads to another event, such as the birth of a child and purchasing diapers.
- Classification: identification of new patterns, such as coincidences between duct tape purchases and plastic sheeting purchases.
- Clustering: finding and visually documenting groups of previously unknown facts, such as geographic location and brand preferences.
- Forecasting: discovering patterns from which one can make reasonable predictions regarding future activities, such as the prediction that people who join an athletic club may take exercise classes.

While data mining products can be very powerful tools, they are not self-sufficient applications. To be successful, data mining requires skilled technical and analytical specialists who can structure the analysis and interpret the output.

Consequently, the limitations of data mining are primarily data or personnel related, rather than technology related (Seifert, 2007).

Although data mining can help reveal patterns and relationships, it does not tell the user the value or significance of the patterns. These types of determinations must be made by the user. Similarly, the validity of the patterns discovered is dependent on how they compare to real-world circumstances. Another limitation of data mining is that while it can identify connections between behaviours and/or variables, it does not necessarily identify a causal relationship.

Data warehousing is a collection of decision-support technologies, aimed at enabling the knowledge worker (executive, manager, and analyst) to make better and faster decisions (Chaudhuri and Dayal, 1997). Recent years have seen explosive growth, both in the number of products and services offered, and in the adoption of these technologies by industry. According to the META Group, the data warehousing market, including hardware, database software, and tools, is projected to grow from $2 billion in 1995 to $8 billion in 1998 (Chaudhuri and Dayal, 1997). A data warehouse could be considered a storehouse, a repository of data collected from multiple, often heterogeneous data sources, and is intended to be used as a whole under one unified schema. A data warehouse provides the option of analyzing data from different sources under the same roof (Osmar, 1999). To facilitate complex analyses and visualization, the data in a warehouse is typically modeled multidimensionally.

Recently, Chau et al. (2002) developed a prototype Decision-Support System (DSS) based on the integration of the data warehouse technology with an On-Line Analysis Processing (OLAP). The result of this integration is a Construction Management Decision Support System (CMDSS) that allows construction managers to view data from various perspectives with significantly reduced query time and therefore to make more effective and faster decisions. According to the authors, the applications of a data warehouse integrated with a DSS in construction management practice are seen to have considerable potential.

2.4 Visualization Support for Infrastructure

Hamming (1973) states, “The purpose of computation is insight, not numbers.” Card et al. (1999) made a similar statement about visualization: The purpose of visualization is insight, not pictures. The main goals of this insight are discovery, decision making, and explanation (Card et al., 1999). A classic study by Larkin and Simon (1987) revealed some reasons why visualizations can be effective. Larkin and Simon, generally, compared the use of diagrams (visual) to solve physics problems with non- diagrammatic (non-visual) representations. Specially, they compared the effort that had to be expended to perform searches, recognition, and inference with and without the diagrams. Their conclusion was that visual representation using diagrams helped in three basic ways:

- Diagrams can group together all information that is used, thus avoiding large amounts of time spent searching for the elements needed to make a problem-solving inference.

- Diagrams typically use location to group information about a single element, thus avoiding the need to match symbolic labels.
- Diagrams automatically support a large number of perceptual inferences, which are extremely easy for humans.

Apparently, visual representation, such as a diagram or map, is more comprehensible than textual description or a written document. Studies have revealed that humans' perceptive abilities are remarkable and are faster than their cognitive system. Thus, users can scan and recognize the salient features of data, such as color, size, shape, location, or texture, quickly and, in turn, easily detect any changes that have occurred (Korde et al., 2005; Shneiderman, 1994; Shneiderman, 1996;).

In the literature about visualization, terms such as scientific and information visualization are commonly used. Both refer to large sets of data and show abstractions. Scientific visualization relies on physical data, such as the human body, the earth, and molecules. This type of visualization is used to discuss common atomic and three-dimensional phenomena such as heat conduction in engines or ozone concentrations in the atmosphere. On the other hand, information visualization is concerned mainly with nonphysical information such as financial data, collections of documents, and project control data. It is useful for revealing patterns, clusters, or gaps and also for monitoring large amounts of data under time pressure for making decisions (Card et al., 1999; Shneiderman, 1996). Data and information can be distinguished from one another: information corresponds to the message(s) extracted from data (Korde et al., 2005).

2.4.1 Visualization Technologies

Over the past decade, a number of visualization techniques have been developed and enhanced in order to achieve a number of objectives and an increased range of applications. Several authors have tried to classify visualization techniques using various schema. The earliest of these was classification by the data type(s) that they can represent, as proposed by Shneiderman (1996), who further suggested another classification framework on the basis of the type of interactive tools offered by a given technique such as overview, zoom and filter, and details-on-demand. The intent of proposing this latter classification was to identify techniques that could fulfill a specific analytical task desired by the user. Different interactive tools offer different analytic capabilities such as clustering, comparing, and identifying patterns within the data, thereby helping users gain deeper insights into the data. In selecting a visualization technique for a specific application, users need to determine two main factors:

- the data type(s) the technique can represent
- the kind of user interaction it offers for analytic purposes

Some researchers have based their analysis on these categories, for example, Qin et al. (2003).

2.4.2 Visualization Applications in Construction

In construction, visualization can be defined as “the art of representing data using suitable visual formats and/or graphical images such that it simplifies and facilitates its interpretation by the intended target audience” (Korde et al., 2005). By the term “intended target audience”, the author means multiple types of audiences ranging from the client to the project team members. This definition is significant because the type of audience determines the type of visual image to be generated.

Visualization systems are urgently needed in construction. Such systems are immensely important during the conceptual stage of the design process because in this stage where significant decisions concerning the future of the project are being made during a very hectic timeframe. Computer-based systems that could render proper visualization of the given specifications and of the project itself could assist the project management team members by quickly increasing their understanding of the design issues and requirements (Rafiq et al., 2005). The lack of good visualization tools may negatively influence the decision-making process and lead to failure in the development or successful completion of the project. Visualization tools allow a visual and more organized presentation of multi-dimensional and multi-criteria design features so that managers can “see” the space available and more efficiently allocate resources (Rafiq et al., 2005).

Bar charts, a scheduling technique, are widely used by construction professionals during the planning stage to quickly represent the total duration of each project activity. As a tool used for comparing actual to planned progress, bar charts can show performance to all project personnel. However, they have limitations: they do not communicate the interrelationships among project activities (Gould and Joyce, 2002), and they do not specify production rates or crew continuity throughout the project's life cycle. They also fail to provide efficient strategies for project overruns, which is a serious issue. Due to these limitations, Russel and Udaipurwala (2002) proposed a visualization environment that visualizes the construction schedule in three different formats: a linear planning chart, a bar chart, and a network diagram. Construction personnel can effortlessly switch from one representation to another. In addition to the power of the tool, the authors mentioned the following advantages to their approach:

- the ability to gain a big picture view of the overall construction strategy
- the ability to drill down into local details of the schedule
- the ability to identify the most effective strategy for corrective action

The sample project described had sufficient scale and complexity to test their proposed approach.

To enhance the visual representation of data and avoid information overload, Songer and Hays (2003) worked with a framework that develops visualization strategies for multi-dimensional construction control data by using a hierarchical tree, a treemaps layout, and other visual aids such as scatterplots and linked histograms. They illustrated an iterative process that implements several principles of visualization theory, including structuring, filtering, editing, and communicating, while considering the level of detail, density, and efficiency of the data representation **(**Figure 2.1)

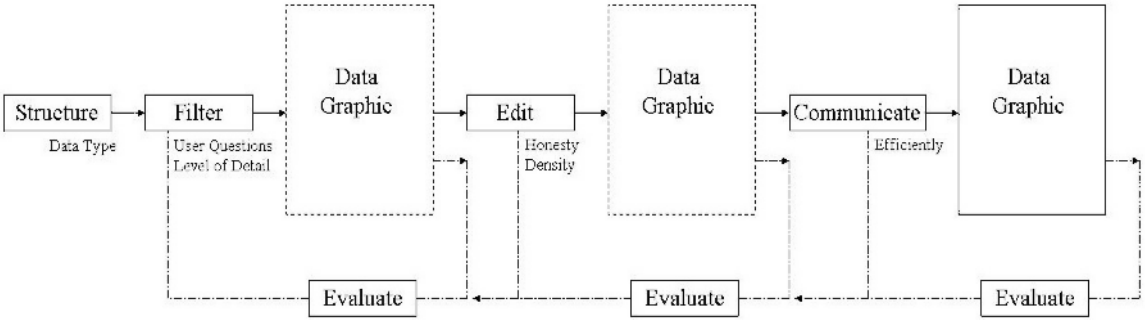


Figure 2.1: Flowchart of Topics Pertinent to Creating Effective Data Graphics (Songer and Hays, 2003)

2.4.3 4D-CAD Visualization

Critical path method (CPM) networks and bar charts are frequently used by construction planners to communicate the proposed schedule for a project. The CPM schedule provides a relatively clear representation of the critical activities and overall timing of all activities. Typically, a construction project consists of a large number of components (e.g., roofs, beams, columns, etc.) that are assigned several activities that make up the total project. However, the CPM schedule does not represent and communicate the spatial or temporal aspects of construction schedules (Koo and Fischer, 2000). Visual representation of the project at different stages, including the progress of the project and the status of site space usage, cannot be provided. Consequently, the optimum way to deliver a particular design cannot be determined from the CPM schedule and bar charts alone because it is difficult to create alternative schedules during the execution of the project.

During the past two decades, three-dimensional (3D) computer-aided design (CAD) technologies have permitted companies to apply 3D-CAD models to construction information in projects (Wang et al., 2004). However, these 3D models by themselves, without the ability to display the exact status of a project at a specific point in time, provide little assistance with progress control due to the lack of data integration and interaction between the 3D model, the schedule information, and other data (Wang et al., 2004).

Project managers have traditionally relied on their innate ability to visualize in order to link and coordinate project documents and schedules (2D) with the construction sequence (3D) (Heesom and Mahdjoubi, 2004). This process includes resource allocation and workspace logistics, which by their nature are highly dynamic. Thus, critical decisions made during construction depend primarily on the experience and judgment of the project managers, but this method has sometimes led to ineffective actions and human error (Chau et al., 2005; Heesom and Mahdjoubi, 2004). Computers have the potential to improve the outcome of critical construction decisions.

The addition of a fourth dimension, i.e., time, to the 3D-CAD technology offers a unique solution to the shortcomings of previous methods. Simply put, 4D-CAD

(3D+time) is a medium that represents time and space (McKinney et al., 1996). First developed in the 1980s, 4D-CAD visualization has been used at various levels of detail, from coordinating and simulating the overall phasing of a project to coordinating the daily work of a group of subcontractors (Heesom and Mahdjoubi, 2004; Ma et al., 2005). 4D-CAD visualization can help represent the construction schedule and process through graphics as well as through 3D models. It can potentially promote true collaboration among project participants and assist in decision making during the different stages of construction.

It is generally recognized that comprehensive construction planning and efficient site utilization are very significant in the site management of construction projects. The increasing complexity of modern construction, coupled with the increasing number of parties involved, requires more effective planning and communication. In 1996, the Center for Integrated Facility Engineering (CIFE) at Stanford University formally used the concept of 4D-CAD for the first time (Wang et al., 2004). The suggested 4D-CAD is capable of attaching time information to the traditional static 3D model, thus allowing all project parties to clearly comprehend the construction plan and minimize potential conflicts on a construction site. Planners can also use what-if analysis to assess and compare several planning options and select a better strategy. The concept of 4D-CAD is described in Figure 2.2 (Wang et al., 2004).

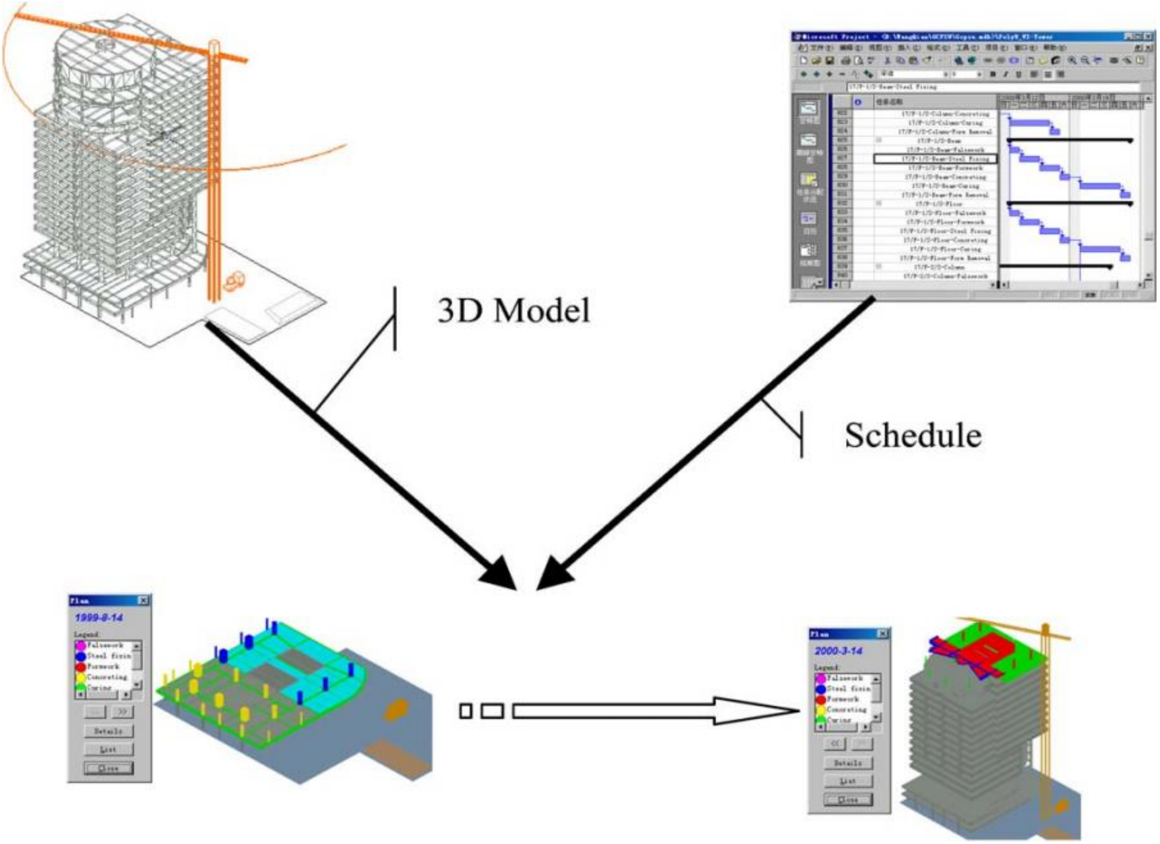


Figure 2.2: The Concept of 4D-CAD (Wang et al., 2004)

Owing to the significant potential of 4D-CAD, several studies have been conducted with respect to this new field during the past decade (Chau et al.,, 2005). Retik et al. (1990) studied the feasibility of using computer graphics in partnership with construction scheduling and explored the functions required. Williams (1996) represented a construction plan graphically with a 4D-Planner in response to project visualization, simulation, and communication needs. Research at the Center for Integrated Facility Engineering (CIFE) laboratory at Stanford University is focuses on developing a comprehensive 4D-CAD model that can help architects, engineers, and contractors simulate and visualize the construction processes and that will consider the smoothness of the dissemination of information to all participants in the project. McKinney et al. (1996) presented a prototype 4D-CAD tool (CIFE 4D-CAD) with visual and communicative functions that would primarily support the interactive exploration of design and construction alternatives, facilitate the decision-making process, and enhance the collaboration between project team members. Their 4D-CAD tool was the final result of linking the 3D-CAD model to CPM schedule in a knowledge-based environment known as D++. Collier and Fischer (1996) developed a software environment that integrates a 3D graphical model and the construction schedule with the assistance of simulation software in order to generate 4D simulations of the construction project. The software was experimented on with the real-life case study of the San Mateo County Hospital in the United States. According to the authors, the study revealed that visual-based scheduling with 4D-CAD models played a major role in reducing coordination and communication problems between clients and contractors and in improving the stakeholders' acceptance of the construction project. In another study conducted by Vaugn (1996), 4D simulation has proven useful as a medium for the evaluation of alternative construction schedules. In 1997 , Adjei-Kumi and Retik (1997) reported on the library-based 4D model PROVISYS for planning and visualizing the construction plan in a virtual reality environment. McKinney et al. (1998) demonstrated the capability of 4D-CAD models to identify potential problems during the project planning stages before the actual construction starts. The main thrust of work in this area sought to add annotations to 4D models that would explain potential construction problems to planners visually, thus making the model more accessible as a support for decision making. Following on this work, Liston et al. (1998) developed a 4D-CAD visual decision-support tool for construction planners that provided visual cues for the quick identification of problem areas.

The use of 4D-CAD for collaboration and communication has received a great deal of attention. McKinney and Fischer (1998) described the current process of project planning as utilizing a “mental 4D model” (Figure 2.3B), depicting the mental association made between the 3D building products and the schedule of activities (Figure 2.3A). The use of mental 4D models allows ambiguity between the visual representations of the construction project and can lead to problems with communication and collaboration between the parties involved in a project, including the client, the contractor, and the sub-contractors. Each party receives project information, including a project schedule, 2D drawings, and a 3D product model, and then builds a mental 4D model of how the building will be built (Figure 2.3C). the end result is often not the same for all parties, which leads to communication difficulties. An actual 4D model can remove these discrepancies and allow all parties to communicate using the same model (Figure 2.3D).

One of the main advantages of 4D-CAD for construction planning is its ability to analyze construction schedules and evaluate their executability. Koo and Fischer (2000) used a case study based on a real project that consists of three identical two-story office buildings to substantiate the effectiveness of the 4D visualization

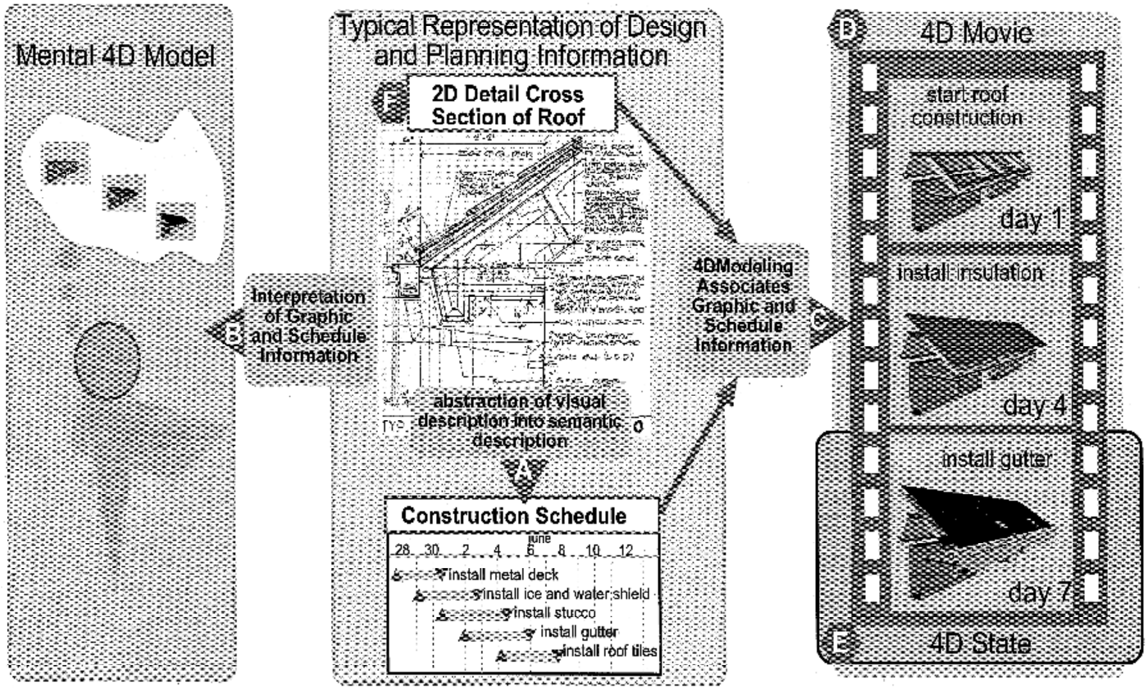


Figure 2.3: Traditional Planning vs. 4D Modeling Processes (McKinney and Fischer, 1998)

model in delivering a construction schedule. For the first building, which was already completed at the time of the study, they created a 4D model to analyze the problems encountered by the construction managers during the actual construction. The overall architecture of the system development is illustrated in Figure 2.4. The main purpose of the comparative analysis of the 4D model was to test the model to determine whether it would be able to anticipate problems and thus enhance the constructability of the two remaining buildings. The study revealed that using a 4D model as an analysis and visualization tool makes the construction schedule more understandable for even relatively inexperienced project participants and makes potential problems or mistakes easier to detect before the construction is even begun.

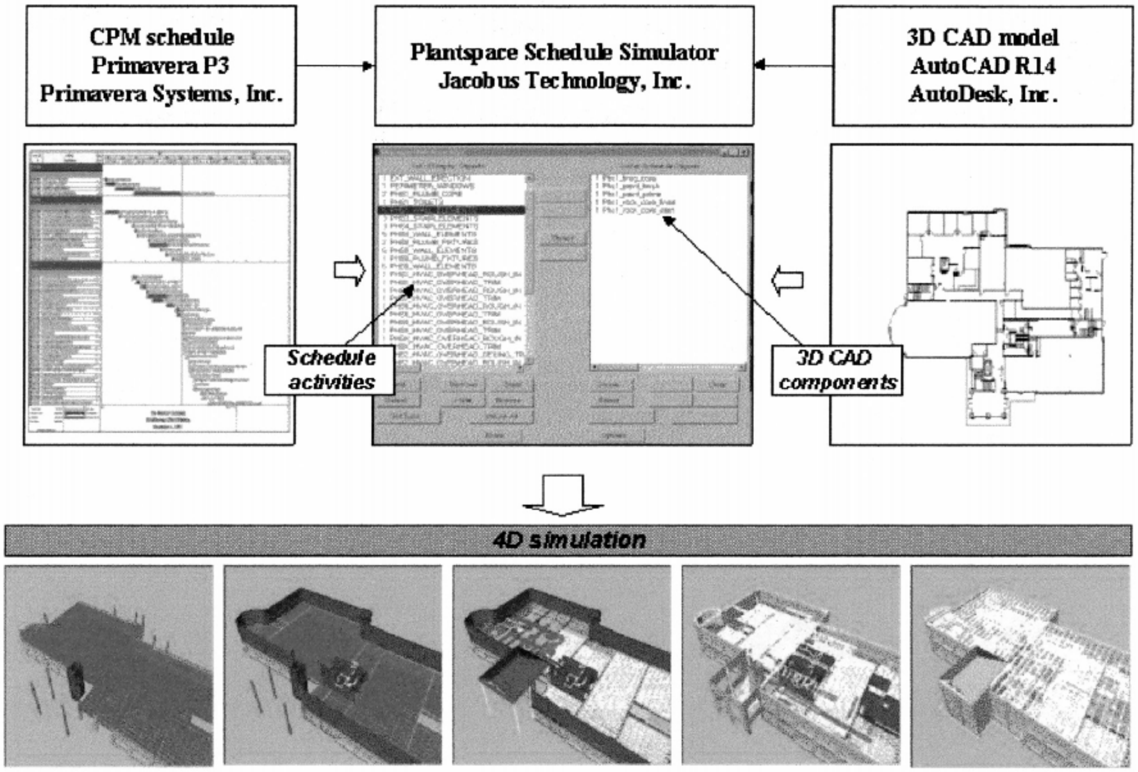


Figure 2.4: Overall System Architecture for 4D-CAD Model Development (Koo and Fischer, 2000)

Webb (2000) envisaged 4D simulations helping to halve the waste costs associated with a construction project. According to Kamat and Martinez (2001), visualizing the construction processes is required for the project participants to virtually view the project environment and interact with the movement of the several resources used during the actual construction. The authors proposed a 3D and trace-driven visualization system designed to meet the unique requirements of visualizing the construction processes and resulting products in 3D virtual space. The system could be considered a 4D-CAD system, but “with a construction-process level of detail rather than a schedule level of detail.” Using a simulation tool, STROBOSCOPE (Martinez, 1996), and 3D-CAD models of resources and the facility, the system was able to perform the following tasks:

- Easy creation of realistic 3D animations for construction operations and equipment
- Virtual analysis for different construction site scenarios
- In-depth insight about future construction projects
- Effortless navigation in 3D virtual space

The study stated that such a system would be a useful tool for planners in order to make efficient decisions prior to the actual construction operations.

2.4.4 Virtual Reality

Virtual Reality (VR) can be defined as a "way for humans to visualize, manipulate, and interact with computers and extremely complex data" (Aukstakalnis and Blatner, 1992). Virtual reality could be broadly described as a set of technologies that utilize computer graphics to create a simulation of an existing reality or a projected reality (Burdea and Coiffet, 2003). Because it allows the computer user to be placed in three-dimensional worlds and to access a fully interactive environment, virtual reality could be considered a major leap in creating interaction with computers and the visualization of information (Aukstakalnis and Blatner, 1992).

The technology was initially born from the merging of many disciplines, including psychology, cybernetics, computer graphics, database design, electronics, multimedia, and telepresence (Warwick et al., 1993). Virtual reality grew out of flight simulation tools developed by the United States army in the 1960s. In 1965, Ivan Sutherland, one of the fathers of virtual reality, presented a paper entitled "The Ultimate Display", which was one of the first attempts to describe virtual reality (Warwick et al., 1993). Three years later, he introduced the first -ever working head-mounted three-dimensional display (Warwick et al., 1993). Eventually, a virtual map of guided walks was produced in the 1970s, and by the end of 1980s, Jaron Lanier coined the term 'virtual reality' (Vince 1995). In the 1990s, with the widespread use of internet, a specific programming language was defined: the Virtual Reality Modeling Language (VRML), which is a standardized definition of three-dimensional space (Sampaio et al., 2004).

In general, the most important features of virtual reality are considered to be immersion and interaction, although there is a third feature of virtual reality that is oftenly neglected: imagination. Therefore, virtual reality is an integrated trio of Immersion-Interaction-Imagination, as shown in Figure 2.5 (Burdea and Coiffet, 2003).

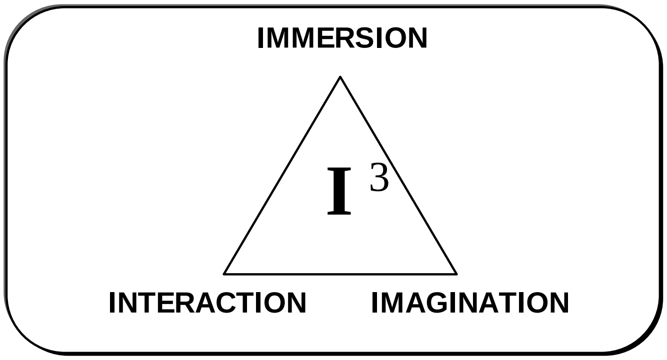


Figure 2.5: Virtual Reality Triangle (Burdea and Coiffet, 2003).

Virtual reality is not just a medium or a high-user interface; it is an exciting technology that offers considerable potential benefits for all stages of the construction process, from initial planning and conceptual design to facility management and operations (Facit Visual Simulation, 2007). The key to its potential lies in its power as a medium for communicating the complex 3D information that defines any construction project. Even if no virtual reality systems are especially designed for the construction industry today, the systems are so generally formed that they can be used in the field of construction. The literature states that the most substantial benefit of virtual reality in construction could be the enhancement of communication that can be facilitated through the visualization of possible project outcomes and that may be shared among the project participants. As a result, several studies have been conducted to examine the increasing demand for this technology in the construction industry.

Virtual reality could assist practitioners in planning and monitoring construction projects by means of visual simulation. The desired simulation could be achieved by the development of a dynamic link-interface between existing scheduling tools and advanced visualization techniques such as virtual reality (Retik, 1997). Retik (1997) presented a computer-based system developed to create a virtual construction project. The approach is based on generating a realistic 3D model of the project components and then simulating the model graphically at different stages of the work progress in order to evaluate planning strategies. The outcome should be enhanced project management and easier identification of possible reductions in the duration and costs.

Site-related activities, such as framework for concrete, site accommodation, temporary services, and fencing, demand effective planning and scheduling in order to avoid costly delays and disputes among project participants. The integration of site-related activities within a virtual reality environment would help architects, engineers, and contractors (AEC) professionals to visualize the actual building works and final product as well as progress in the organization of the site under different scenarios. Retik and Shapira (1999) studied a VR-based model that integrates site-related activities into the planning and scheduling of the entire construction project. The model uses visualization and a knowledge-based simulation of the progress of the work to achieve the required integration. 3D computer graphics and constant simulation of the progress of the work facilitates the spatial planning for site-related activities. The prototype systems components are shown in Figure 2.6.

Virtual reality techniques such as geometric modeling may be utilized for visual simulation of the construction process. Sampaio et al. (2004) took a case study of a common external wall with two brick panels to create a virtual model that is used as a didactic tool for civil engineering students. The resulting interactive system helped in making the construction sequence and wall elements more comprehensible to the students and confirms the authors’ theories.

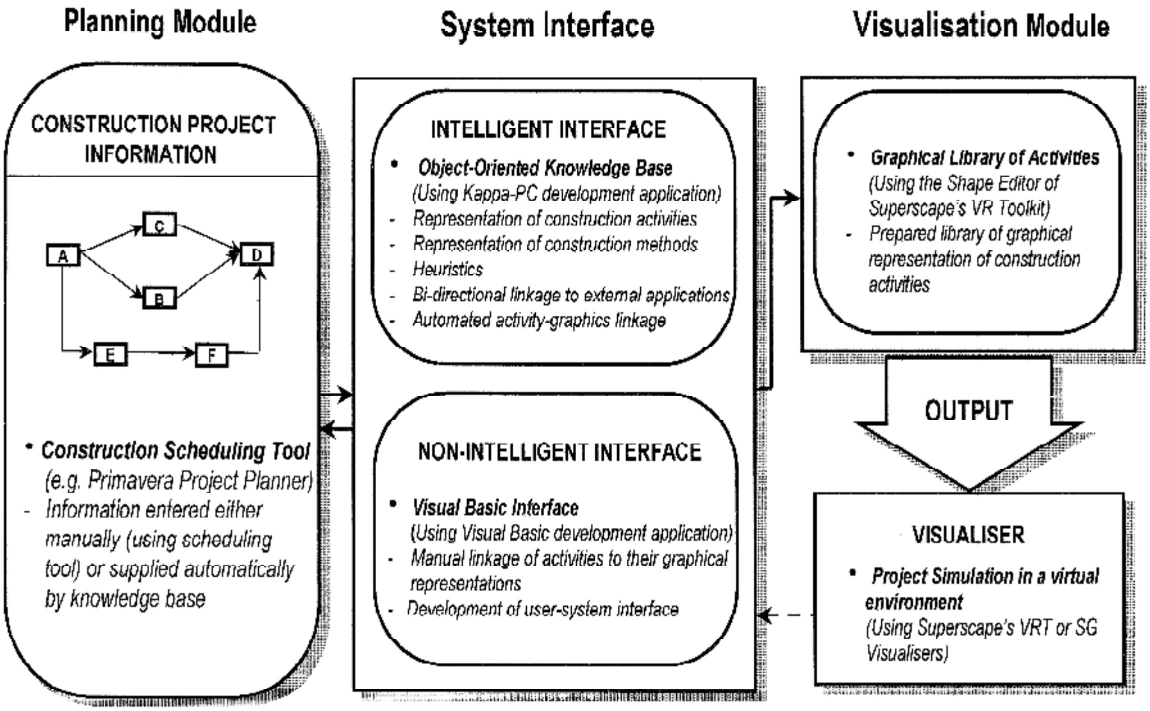


Figure 2.6: System Components and Operations (Retik and Shapira, 1999).

2.5 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) were one of the fastest growing computer-based technologies of the 1990s (Jeljeli et al., 1993). In general, geographic information science is the discipline that promotes an understand ing of the world by describing and explaining human relationships with the Earth (Poku and Arditi, 2006). According to the Environmental Systems Research Institute (ESRI), a GIS can be defined as "an organized collection of computer hardware, application software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographic referenced information" (ESRI, 2000).

In the last decade, Geographic Information Systems have emerged as an essential tool for urban and resource planning and management. Their capacity to store, retrieve, analyze, model, and map large areas and huge volumes of data has led to an extraordinary proliferation of applications. Geographic Information Systems are being used in diverse application areas related to construction, such as utilities management, landscape assessment and planning, transportation and infrastructure planning, construction scheduling and progress control, facilities management, real estate analysis, and land resources management.

The 1988 GIS core business was estimated to have been $529 million. This amount was projected to grow by 32% annually through 1993. The total GIS industry was also predicted to expand by about 22% annually, to reach a total of about $11 billion by 1993 (Daratech Inc., 2007). In 2003, the total GIS core business revenue was estimated to have been $1.75 billion with an 8% growth rate, as compared to a 2.4% rate ($1.6 billion) in 2002 (Daratech Inc., 2007).

This trend has not been reflected directly in the construction industry. Most of the computer technologies investigated by construction professionals focus on the descriptive aspect of the data, although a vast amount of construction data can be spatially referenced. Unlike Database Management Systems (DBMS), which deal only with descriptive data and Computer Aided Design (CAD), that depends on spatial data, a GIS can present both spatial and nonspatial data to from different sources, and can store, analyze, and present it systematically (Jejeli et al., 1993). Thus, a GIS is both a database system with the specific capabilities of dealing with spatially referenced data, and a set of operations for working with the data (Poku and Arditi, 2006). Therefore, GIS can reveal important new information that can lead to better decision making.

A more comprehensive and easier way to define GIS is one that looks at the disposition of the layers of its data sets, as shown in Figure 2.7: "Group of maps of the same portion of the territory, where a given location has the same coordinates in all the maps included in the system" (ESRI, 2000). In this way, it is possible to analyze thematic and spatial characteristics in order to obtain better knowledge of a specific zone.

A GIS was adopted by Oloufa et al. (1994) to develop a system that is capable of storing descriptive soil data pertaining to boreholes and to link the descriptive data to the corresponding geographic locations of the boreholes. Moreover, the system provided a graphical user interface (GUI) that facilitates the input, and output of the data, and the display of the boring logs. The system could be considered a graphical operating environment that allowed the user to correlate the construction sites and the subsurface conditions by displaying both the boring logs and a map graphically on the computer monitor. The authors concluded that an integrated GIS could improve the efficiency of the preliminary site investigation, as well as estimating and planning phases of construction projects.

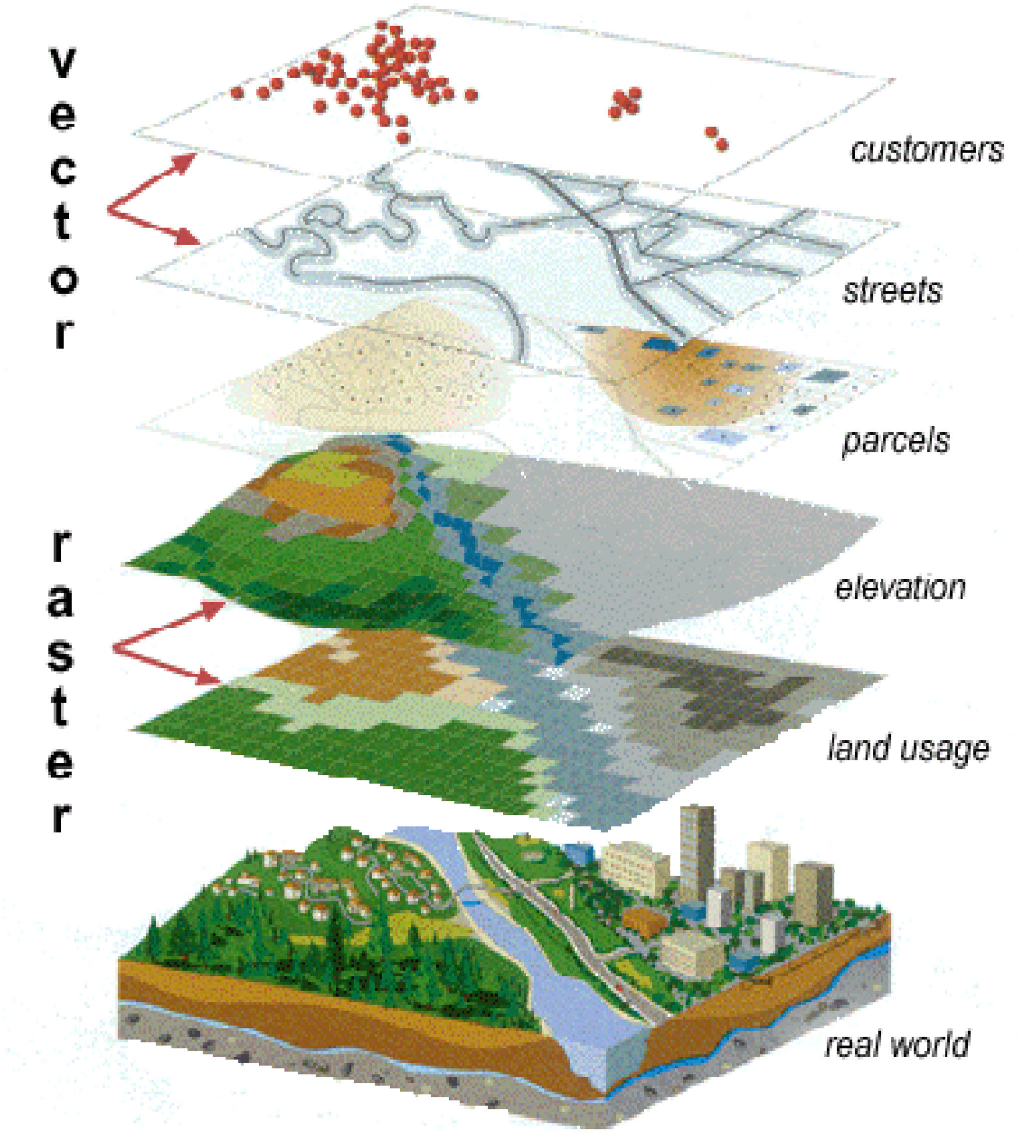


Figure 2.7: The Concept of Layers (ESRI, 2000)

Using a GIS-based environment to develop systems proved beneficial for solving construction site layout problems and facilitates decision-making in the early stages of construction projects. Cheng and O'Connor (1996) developed an automated site layout system called ArcSite that was designed to solve the layout problems in the temporary facilities (TFs) and to eliminate the site choice of the TF as an ill-structured problem. The system adopts a Geographic Information System (GIS) software package, ArcInfo, to help the parties involved in the site planning identify suitable areas for temporary facilities in order to minimize construction conflicts and improve the efficiency of the project. In a similar study, Cheng and Yang (2001) presented a system called MaterialPlan to help planners in quantity takeoffs and assessing materials layout design. The system integrates a GIS-based cost estimate system with construction scheduling to allow managers to locate materials on a construction site efficiently.

GIS have been used to provide consistent information management systems for architectural design, engineering, and construction project processes. Sun and Hasell (2002) presented an integrated framework that exploited GIS technology and software (ArcView) to match a building project process as its operation is based on physical assets covering a specific spatial area. The idea behind the development of the system was to feed the system data for a specific project and then exploit the abilities of the GIS to manage, manipulate, and display spatially referenced data. The system was tested for functions directly related to the building project, such as project planning, preliminary cost estimation, project site condition analysis, and change order analysis. As stated by the authors, the GIS-based integrated information system strongly promotes the concepts of automated acquisition and storage of data to support project management.

GIS have also played major roles in monitoring construction progress and constructability by integrating spatial and nonspatial data into a unique environment that can present the construction progress in a graphical manner. Cheng and Chen (2002) developed an automated schedule-monitoring system called ArcShed to enhance the control of the erection process for the construction of a precast building and to monitor the construction progress in real time. The proposed system was composed of a GIS integrated with a database management system. A bar code system with wireless RF transmission technology was used to improve the efficiency of the data collection.

Recently, a system called Progress Monitoring System with Geographic Information Systems (PMS-GIS) was developed by Poku and Arditi (2006) to visualize construction progress in three dimensions, side by side with the CPM construction schedule. PMS-GIS was based on existing software. The architectural design was generated by AutoCAD, and the schedule was created by a project management software (P3). This information was then plugged into a GIS package called ArcGIS so that the project parties could see simultaneous detailed views of the spatial and non-spatial aspects of the project (Figure 2.8). Because it can communicate the schedule/progress information effectively to all project participants, PMS-GIS can be used in all phases of the construction process, including planning, design, and day-to-day decision making during the actual construction. It can also give specific information about equipment, labor, costs, etc., and allow the parties involved in the project to view in great details general pictures of the whole project or specific ones of the portion of it directly related to them.

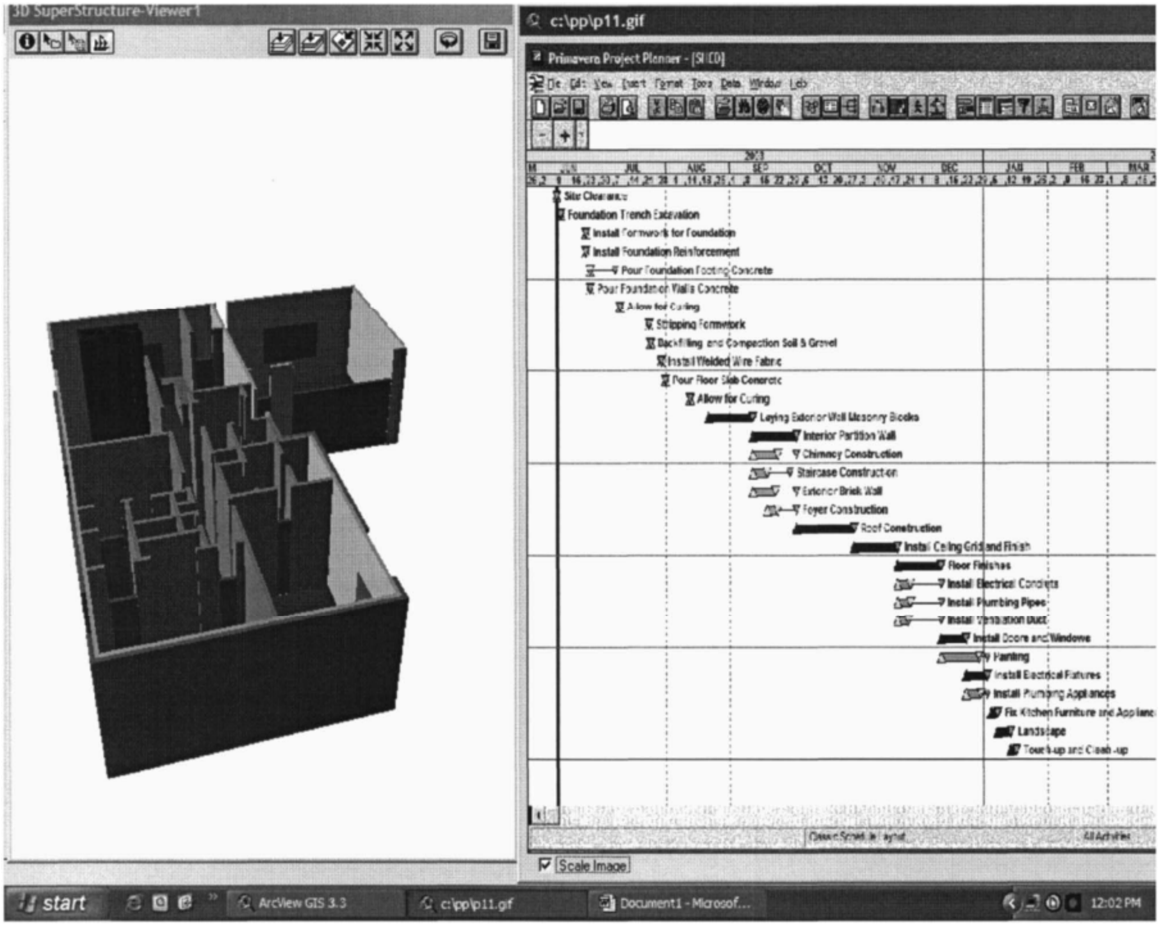


Figure 2.8: 3D View of Spatial and Non-Spatial Aspects (Poku and Arditi, 2006)

Motivated by the lack of an effective tool in construction industry to minimize the amount of material wastage, Li et al. (2005) substantiated a study that mainly aimed to enhance the crew-based barcode system and facilitate material and equipment management. The proposed prototype system utilized Global Position System (GPS) and Geographic Information System (GIS) technology in order to control and reduce construction waste and to increase the efficiency of onsite material and equipment management. During the case study problem, the results were satisfied and showed that the GPS-and-GIS integrated system was useful in improving the construction efficiency and minimizing the amount of waste material onsite.

GIS have also been used to facilitate the decision-making process. Li et al. (2004) discussed the design and use of spatial decision-support systems (SDSS) to assist property professionals in their decisions concerning locations. The authors integrated a decision-support system (DSS), Excel, with a GIS, MapObject, to develop a simple and inexpensive SDSS (Figure 2.9). The proposed SDSS was capable of addressing spatial problems related to the locations of properties and of displaying relevant information such as costs, income, and locations on separate sheets for decision-making purposes.

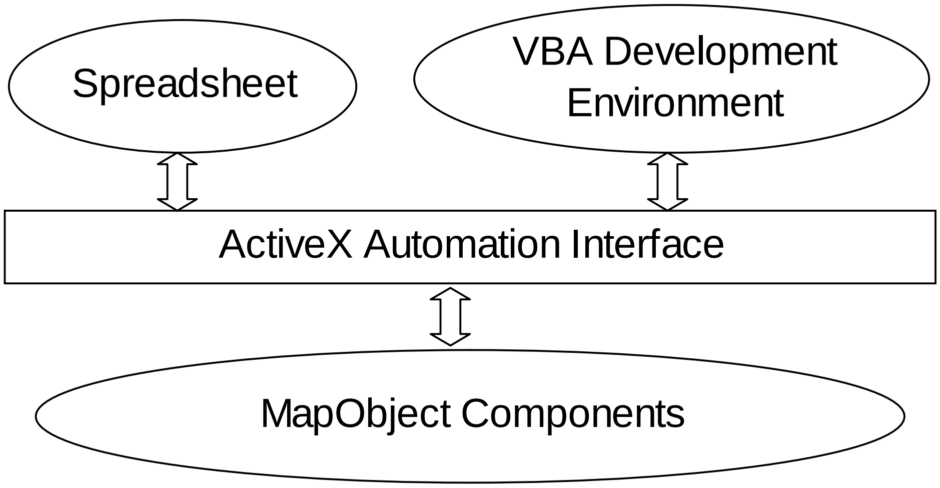


Figure 2.9: Development Environment for the SDSS (Li et al., 2004).

GIS can also support decision making in the management of municipal infrastructure. Vanier (2004) provided a review of the use of GIS technology as a framework for decision-support tools for municipal infrastructure managers, and more specifically, for tools to assist them in prioritizing infrastructure maintenance and capital renewal. Her review shed light on opportunities for research and development and identified the advantages and disadvantages of using the technology. Many large Canadian municipalities have realized the benefits of using GIS and are attempting to integrate this tool into enterprise solutions for managing municipal infrastructure (Vanier, 2004). Furthermore, GIS technology has proven to be capable of managing, querying, visualizing, and analyzing municipal asset data. Halfawy (2004) addressed the important role of GIS technology in enhancing the asset management process and highlighted the data requirements of GIS-based asset management systems. His report also discussed the interoperability and spatial data standards from the perspective of municipal asset management. Recommendations that can lead to developing fully integrated and interoperable municipal GIS-based asset management systems are presented at the end of his report.

A GIS is a very powerful tool for evaluating and planning utility network improvements and for supporting maintenance management systems. According to McKibben and Davis (2002), the integration of GIS, with Computerized Maintenance Management Systems (CMMS) has shown significant benefits for both public and private water utilities. Typically, maintaining utility networks involves several challenges due to their scattered nature, including communication difficulties between maintenance crews and costly travel time. The integration of GIS with CMMS can overcome these challenges and provide identified business benefits, including the following (Mckibben and Davis, 2002):

- Provide map display of the utility, which can be used to plot the location of the problems and show all current and past work orders
- Route crews to the work locations and reduce travel time
- Schedule multiple maintenance tasks in a specific area.

Hegazy (2006) proposed a model that exploits the capabilities of GIS technology and optimization techniques to optimize and visualize infrastructure maintenance programs for scattered sites. A new Distributed Scheduling Method (DMS) (Hegazy et al., 2004) is used to plan available resources and meet constraints. A computer software program, BAL, plays a major role in the model by facilitating the optimization tasks through a non-traditional optimization technique, genetic algorithms (GA). To incorporate GIS features into BAL, non-expensive GIS software, MS MapPoint 2002, has been integrated into BAL through Visual Basic code. Based on GA random procedures, an optimum work schedule is determined and a layer of GIS information is generated. This layer of information contains the start and finish dates for the activities at the various sites along with the assigned crews and is then used to clearly represent the work assignment for all parties in the project, as shown in Figure 2.10.

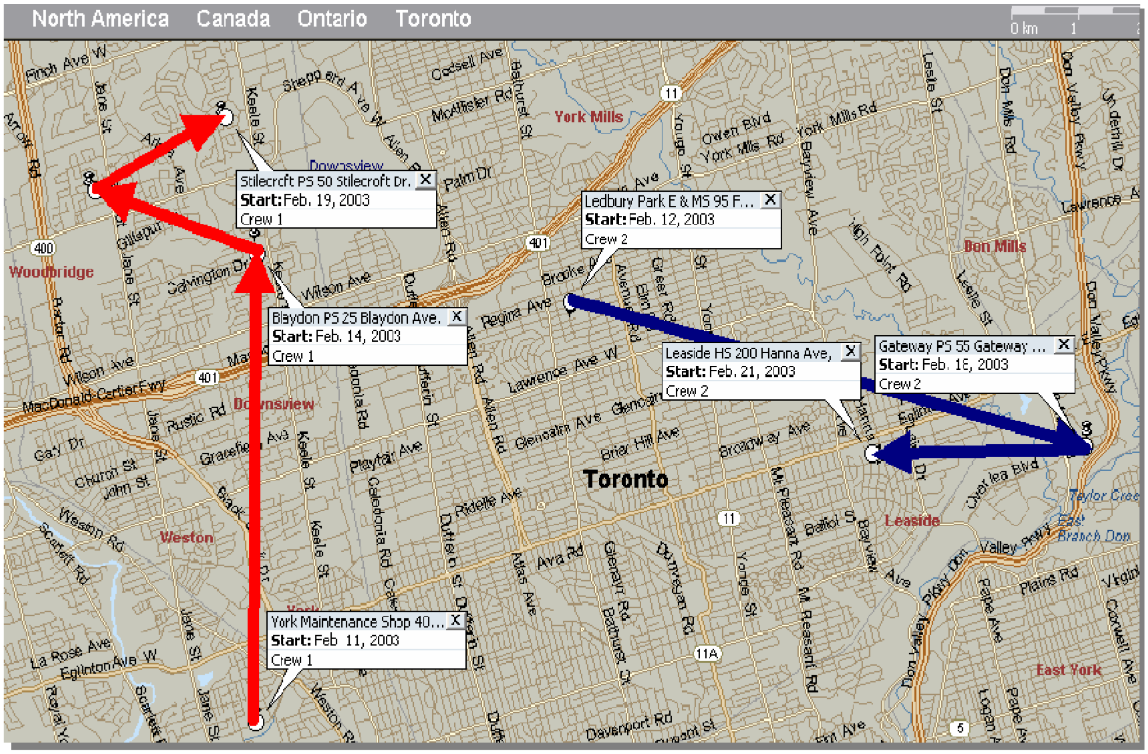


Figure 2.10: Crew Assignment Map (Hegazy, 2006).

The developers used the GIS technology to find optimal solutions for problems related to site selection for long-term capital investment, such as shopping malls. Cheng et al. (2007) presented a GIS-based system that combines spatial (geographical) and non-spatial (market-oriented) data to create visualized information that can be comprehensibly analyzed during the decision-making steps. The developed system used electronic mapping technology to produce interactive multi-layer maps so that queries can be set to find optimal solutions for four location problems, including the minimum distance, maximum demand coverage, maximum income coverage, and the optimal centre. Such illustrative maps, shows the capabilities of GIS to help decision makers find satisfactory solutions for their problems.

Recently, virtual GIS based on a 3D geo-processing methodology and the internet environment have emerged. Virtual reality offers new and exciting opportunities to visualize 3D GIS data (Verbree et al., 1999). 3D GIS display and analysis tools have become more widely accessible to mainstream practitioners. These 3D GIS tools allow users to generate fly-through of high-resolution scenes for presentation, to visualize newly planned buildings, and to consider changes in the landscape (Poku and Arditi, 2006).

To support the interaction of 3D GIS within a VR-environment, Verbree et al. (1999) proposed a system called Karma VI that links existing GIS to VR technology to support the design, development, and presentation of large infrastructure plans in the Netherlands. The system is considered a multi-view approach that uses three types of visualization:

- a plan view to display the data as a conventional map
- a model view to provide a 3D bird-eye's view of the 3D representation of the data
- a world view to give a photo-realistic 3D display

The authors conclude that the operational use of the system leads to a great understanding of the infrastructure plans.

2.6 Conclusion

The construction industry in general and infrastructure management in particular are characterized by large and interrelated data. In this chapter, several management practices and visualization technologies have been reviewed. GIS technologies have proven to be a suitable solution for several problems related to decision making. The integration of GIS with information management tools, such as spreadsheets, can also be promising solutions for facilitating decision making related to scattered facilities.

Chapter 3

Data Collection and Data Management Needs

3.1 Introduction

This chapter introduces the process used in this study to collect a large sample of infrastructure maintenance data for one of the largest building-owner organizations, the Toronto District School Board (TDSB). Various levels of management and reporting needs were also identified based on extensive discussions with experienced personnel in the Design and Services Department and Capital Replacement Department of the TDSB. The data collection and preliminary analysis are discussed in this chapter. The reporting needs are considered later in Chapter 4 in which the development of a proper data management model is presented.

3.2 Toronto District School Board (TDSB)

The Toronto District School Board (TDSB), the data source, is considered to be one of the largest school boards in North America. The TDSB owns a substantial number of building assets, ranging from schools to administrative buildings, that are scattered across Metropolitan Toronto. Maintaining 565 schools and 95 administrative buildings in acceptable running conditions has become a challenging task that requires significant funds and efficient management. To upgrade and maintain its deteriorating buildings, the TDSB administers a $50 million annual infrastructure program that involves about 800 small reconstruction projects (Attalla et al., 2004). These projects range from modifications, renovation, and rehabilitations, to new construction. Having handled simultaneous projects with different scopes for many years, the TDSB has become very experienced in delivering successful projects either in-house or by outside contractors.

Rather than assigning the yearly $50 million budget directly to projects, the board distributes the budget among different building components and their sub-components. Table 3.1 shows the model used to allocate these budget amounts (Attalla et al., 2000). The budgets for the components are then allocated to projects based on priorities, which are determined based on input from inspection personnel and with the use of a computerized system (RECAPP®) for Facility Life Cycle analysis. This process ensures that the most critical needs are addressed before the budget is exhausted. Through a lengthy and costly process of visual inspection, the critical components of the different buildings that need replacement are identified. Decisions are then made by the Capital Replacement Department (CRD) depending on the output from RECAPP® and implemented accordingly.

Table 3.1: Budget Distribution Model (Attalla et al., 2000)

Components	Subcomponents	Percentage of yearly budget
Primary structure (exterior)	Foundations, substructure, superstructure, windows, and roofing	24%
Secondary structure (interior)	Substructure, partitions and doors, wall finishes, and floor	7%
Mechanical	Conveying, plumbing, heating, ventilation, cooling, boilers, pools, and extinguishing system	23%
Electrical	Distribution, light/power, communication, detection, and alarm, emergency power, and transformers	30%
Site	Parking, paved play area, play fields, drainage, playscape, fencing, and regulatory requirement	13%
Program contingency	_	3%

In addition to the CRD, the TDSB also has a large Preventive Maintenance Department (PMD) that is responsible for day-to-day maintenance and repair activities for all the buildings. It responds to urgent needs and also provides periodic maintenance. This department has significant expertise in variety of fields and also uses an expensive computerized tool, Systems Applications and Products (SAP), to fully document and interact with all maintenance work orders. SAP is an Enterprise Resource Planning (ERP) software system that is applied on the whole TDSB intranet to integrate and facilitate the automation of many functions, such as payroll, invoicing, and contracts. It also records all details about resources and work orders.

In recent years, to save money, the TDSB has downsized its CRD. They therefore depend heavily on the Preventive Maintenance Department to maintain their assets. The downsizing, however, greatly affected the ability of the Capital Replacement Personnel to visit the schools frequently to inspect their condition, identify the critical items, and properly allocate the replacement budget.

The huge number of buildings and facilities owned by the TDSB has mandated the proper referencing and categorizing of assets. The TDSB has adopted a unique, convenient referencing method to support all educational, administrative, and management activities across the organization. The city of Toronto has been divided into four areas that reflect different geographical locations: northeast (NE), northwest (NW), southeast (SE), and southwest (SW), as shown in Figure 3.1. Each area consists of six sub-areas that are referred to as school families, and each school family contains approximately 24 schools of different types, sizes, ages, and conditions. Each family is assigned a group of experienced trades personnel in various categories (roofing, carpentry, mechanics, etc.), who carry out the regular preventive maintenance. Each school is defined by its unique ID number, family, type, construction year, size (m^2), original construction cost, and address. Figure 3.2 shows the hierarchy of TDSB schools.

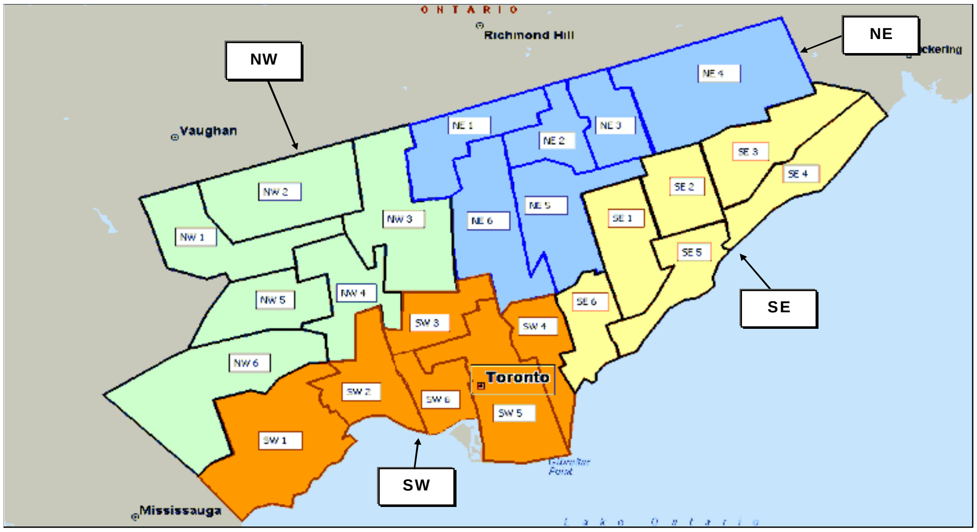


Figure 3.1: Areas and Families of Schools According to the Toronto District School Board (TDSB)

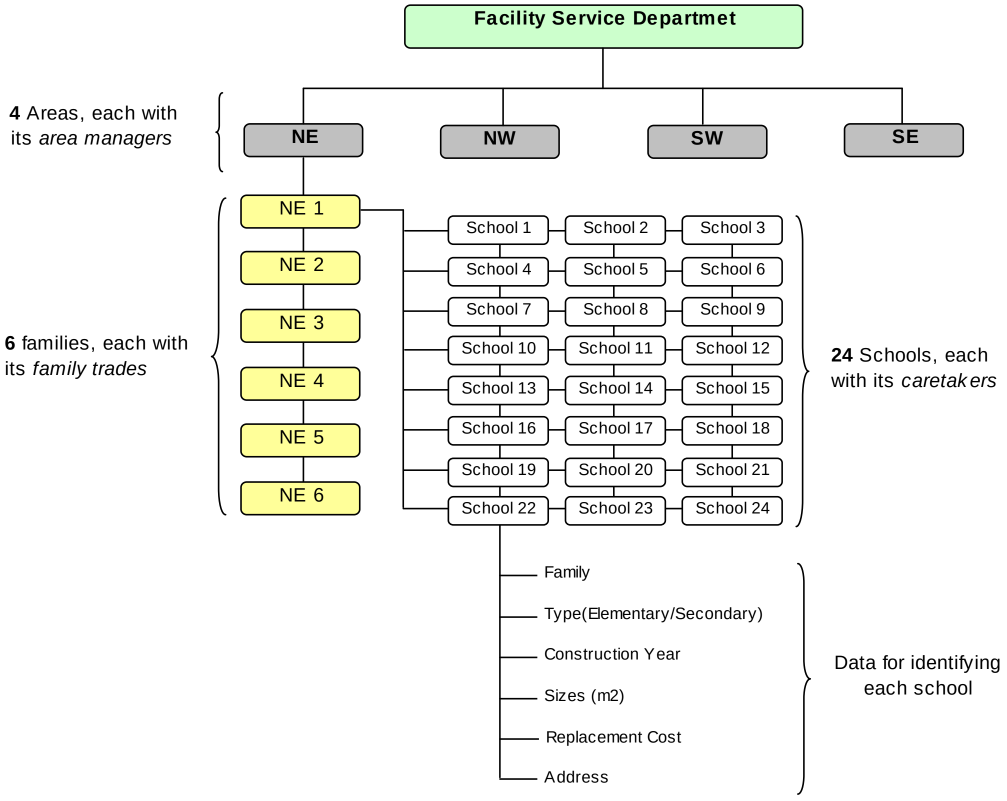


Figure 3.2: Hierarchy of the TDSB Schools

For maintenance and repairs, the responsibilities are distributed at different levels. At the lowest level, each school is assigned a number of caretakers (one to three, depending on the size of the school) who are in charge of daily checking and minor maintenance works that require no specific expertise. The caretakers can contact the family trades personnel in case there is an urgent maintenance need such as a roof leak or mechanical failure. In such a situation, the family trades personnel can either fix the problem or, if the task is large and requires a specific work order, design work, or an external contract, refer it to the central office. The family trades personnel report to the family manager, who in turn reports to his area manager. All the area managers report to the head of the Facility Service Department.

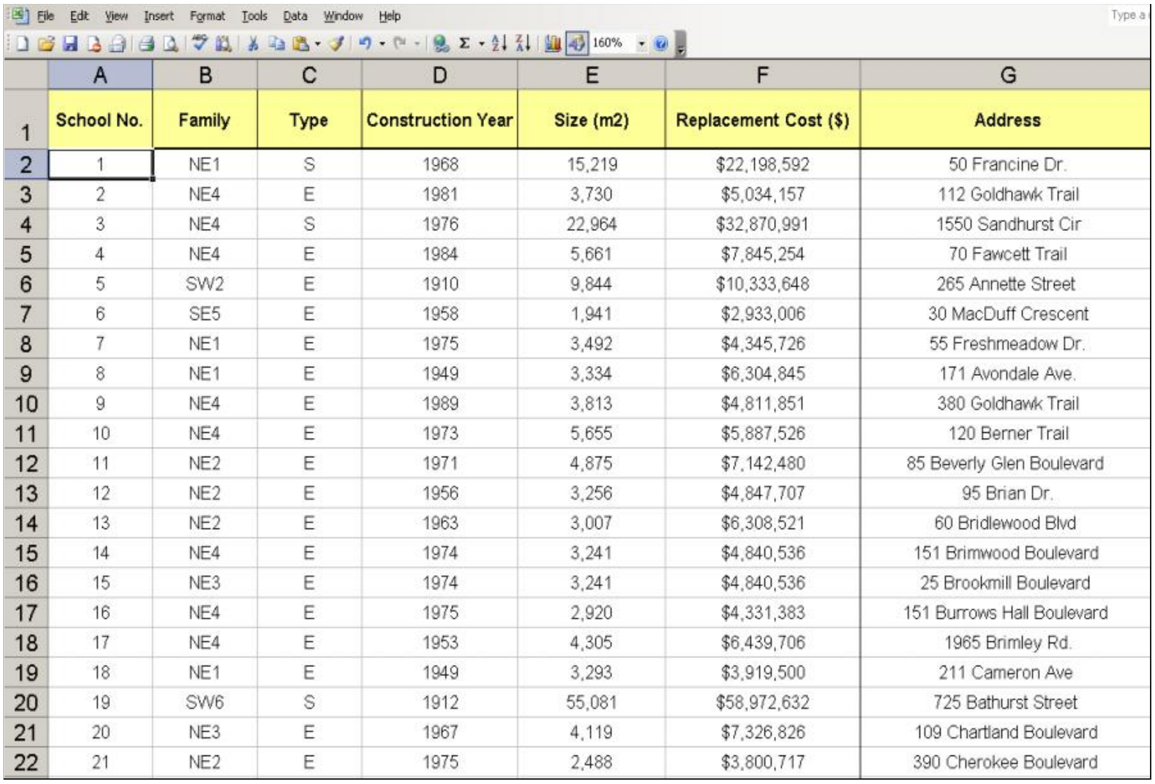
With this reporting structure, different data is collected and viewed at different levels. To facilitate decision making at all levels, it is important that a system provides quick analysis of the large amount of data and then produce suitable reports in different formats such as text, charts, and maps. It is also important that it provides a simple means of using this data to support capital replacement decisions, which have been significantly affected by downsizing.

3.3 Data Collection and Preliminary Analysis

The TDSB has a huge amount of data about maintenance and repair work orders, and was asked to provide a sample of the data in order to facilitate the development of a suitable data management model. Accordingly, maintenance records for 93 schools from different families were obtained from the SAP system at the TDSB. Two types of data were collected:

- General data about the school type, size, and location
- Specific data about the complete maintenance work orders

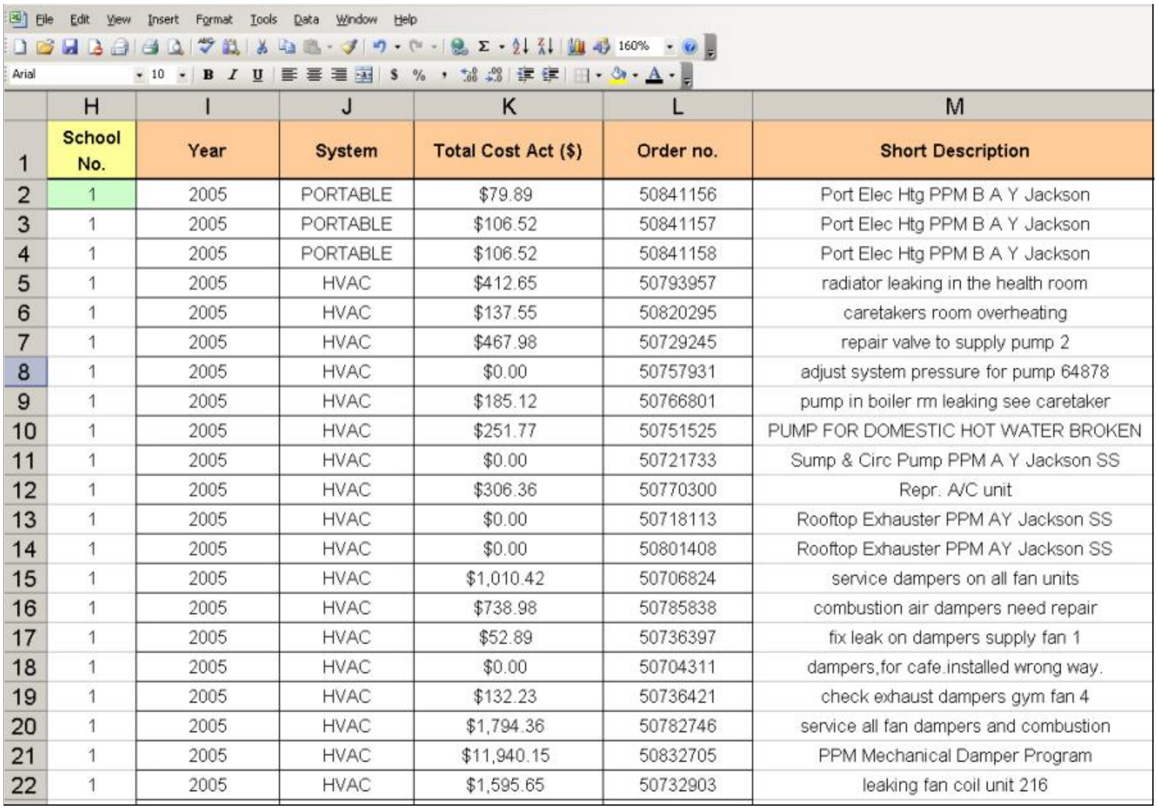
A sample of the general data for the 93 schools is shown in Figure 3.3.



School No.	Family	Type	Construction Year	Size (m2)	Replacement Cost ($)	Address
1	NE1	S	1968	15,219	$22,198,592	50 Francine Dr.
2	NE4	E	1981	3,730	$5,034,157	112 Goldhawk Trail
3	NE4	S	1976	22,964	$32,870,991	1550 Sandhurst Cir
4	NE4	E	1984	5,661	$7,845,254	70 Fawcett Trail
5	SW2	E	1910	9,844	$10,333,648	265 Annette Street
6	SE5	E	1958	1,941	$2,933,006	30 MacDuff Crescent
7	NE1	E	1975	3,492	$4,345,726	55 Freshmeadow Dr.
8	NE1	E	1949	3,334	$6,304,845	171 Avondale Ave.
9	NE4	E	1989	3,813	$4,811,851	380 Goldhawk Trail
10	NE4	E	1973	5,655	$5,887,526	120 Berner Trail
11	NE2	E	1971	4,875	$7,142,480	85 Beverly Glen Boulevard
12	NE2	E	1956	3,256	$4,847,707	95 Brian Dr.
13	NE2	E	1963	3,007	$6,308,521	60 Bridlewood Blvd
14	NE4	E	1974	3,241	$4,840,536	151 Brimwood Boulevard
15	NE3	E	1974	3,241	$4,840,536	25 Brookmill Boulevard
16	NE4	E	1975	2,920	$4,331,383	151 Burrows Hall Boulevard
17	NE4	E	1953	4,305	$6,439,706	1965 Brimley Rd.
18	NE1	E	1949	3,293	$3,919,500	211 Cameron Ave
19	SW6	S	1912	55,081	$58,972,632	725 Bathurst Street
20	NE3	E	1967	4,119	$7,326,826	109 Chartland Boulevard
21	NE2	E	1975	2,488	$3,800,717	390 Cherokee Boulevard

Figure 3.3: Sample of the General Data about the TDSB Schools

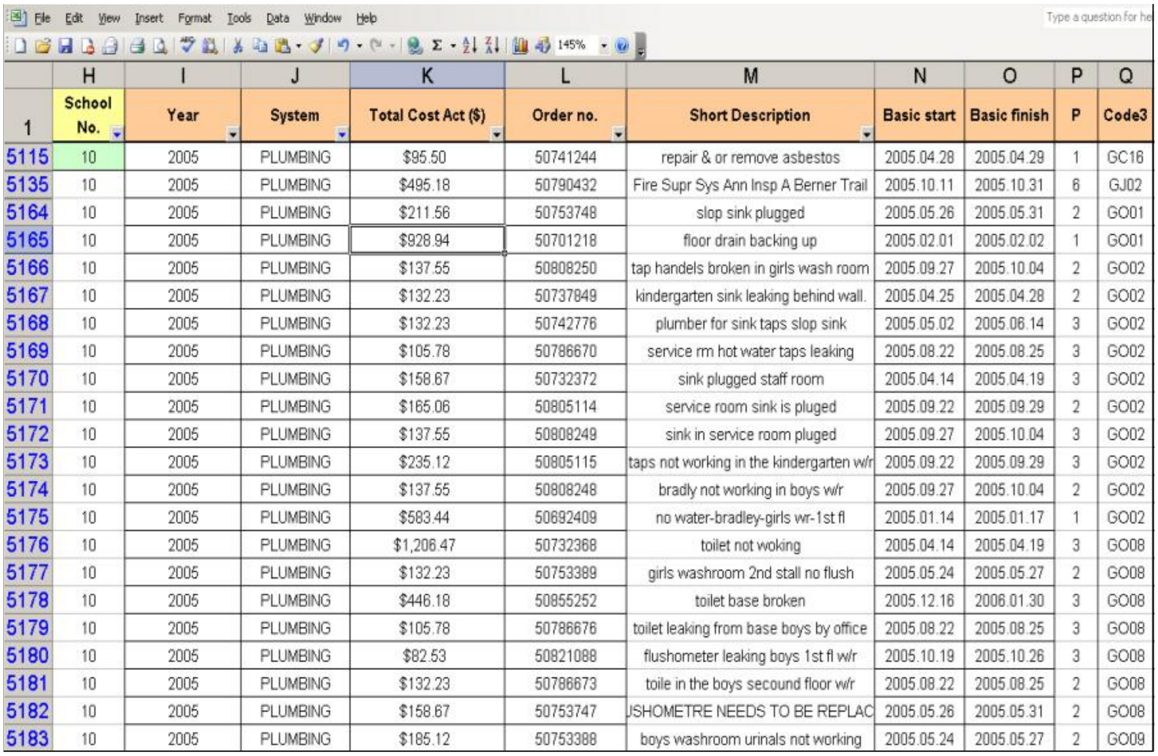
The specific data in Figure 3.4 relate to the maintenance records for the same set of sample schools (93) that was obtained from the SAP system for 2005 and 2006. Data were collected for two full years to ensure that any conclusions of the study are consistent from one year to another. A sample of the specific data is shown in Figure 3.4. All the information shown in Figure 3.4 relates to school 1. Similar data was obtained for the remaining 92 schools. The sample includes information about work orders for all 93 schools, such as the school number (corresponding to the general data school number), a short text description of the work order, its priority, the total actual cost (in Canadian dollars), the code and object for the detailed hierarchy match, and the year the work order was completed.



	H	I	J	K	L	M
1	School No.	Year	System	Total Cost Act ($)	Order no.	Short Description
2	1	2005	PORTABLE	$79.89	50841156	Port Elec Htg PPM B A Y Jackson
3	1	2005	PORTABLE	$106.52	50841157	Port Elec Htg PPM B A Y Jackson
4	1	2005	PORTABLE	$106.52	50841158	Port Elec Htg PPM B A Y Jackson
5	1	2005	HVAC	$412.65	50793957	radiator leaking in the health room
6	1	2005	HVAC	$137.55	50820295	caretakers room overheating
7	1	2005	HVAC	$467.98	50729245	repair valve to supply pump 2
8	1	2005	HVAC	$0.00	50757931	adjust system pressure for pump 64878
9	1	2005	HVAC	$185.12	50766801	pump in boiler rm leaking see caretaker
10	1	2005	HVAC	$251.77	50751525	PUMP FOR DOMESTIC HOT WATER BROKEN
11	1	2005	HVAC	$0.00	50721733	Sump & Circ Pump PPM A Y Jackson SS
12	1	2005	HVAC	$306.36	50770300	Repr. A/C unit
13	1	2005	HVAC	$0.00	50718113	Rooftop Exhauster PPM AY Jackson SS
14	1	2005	HVAC	$0.00	50801408	Rooftop Exhauster PPM AY Jackson SS
15	1	2005	HVAC	$1,010.42	50706824	service dampers on all fan units
16	1	2005	HVAC	$738.98	50785838	combustion air dampers need repair
17	1	2005	HVAC	$52.89	50736397	fix leak on dampers supply fan 1
18	1	2005	HVAC	$0.00	50704311	dampers,for cafe.installed wrong way.
19	1	2005	HVAC	$132.23	50736421	check exhaust dampers gym fan 4
20	1	2005	HVAC	$1,794.36	50782746	service all fan dampers and combustion
21	1	2005	HVAC	$11,940.15	50832705	PPM Mechanical Damper Program
22	1	2005	HVAC	$1,595.65	50732903	leaking fan coil unit 216

Figure 3.4: Sample of Specific Maintenance Data for School 1

Acquiring of the specific data was a significant task due to the amount and confidential nature of the data. A total of about 44,512 work order records were extracted from SAP for 2005 and 2006. The generation of such detailed information took some time to generate due to the sheer volume of the data and the required level of detail needed for this study. Producing the data in Excel format was also cumbersome and required considerable manipulation. To illustrate the level of detail and complexity of this data, Figure 3.5 shows all the work orders for school 10 for only one component (plumbing) in 2005. This degree of data complexity also applies to all the building components for the entire set of 93 sample schools.



	H	I	J	K	L	M	N	O	P	Q
1	School No.	Year	System	Total Cost Act ($)	Order no.	Short Description	Basic start	Basic finish	P	Code3
5115	10	2005	PLUMBING	$95.50	50741244	repair & or remove asbestos	2005.04.28	2005.04.29	1	GC16
5135	10	2005	PLUMBING	$495.18	50790432	Fire Supr Sys Ann Insp A Berner Trail	2005.10.11	2005.10.31	6	GJ02
5164	10	2005	PLUMBING	$211.56	50753748	slop sink plugged	2005.05.26	2005.05.31	2	GO01
5165	10	2005	PLUMBING	$928.94	50701218	floor drain backing up	2005.02.01	2005.02.02	1	GO01
5166	10	2005	PLUMBING	$137.55	50808250	tap handels broken in girls wash room	2005.09.27	2005.10.04	2	GO02
5167	10	2005	PLUMBING	$132.23	50737849	kindergarten sink leaking behind wall.	2005.04.25	2005.04.28	2	GO02
5168	10	2005	PLUMBING	$132.23	50742776	plumber for sink taps slop sink	2005.05.02	2005.06.14	3	GO02
5169	10	2005	PLUMBING	$105.78	50786670	service rm hot water taps leaking	2005.08.22	2005.08.25	3	GO02
5170	10	2005	PLUMBING	$158.67	50732372	sink plugged staff room	2005.04.14	2005.04.19	3	GO02
5171	10	2005	PLUMBING	$165.06	50805114	service room sink is pluged	2005.09.22	2005.09.29	2	GO02
5172	10	2005	PLUMBING	$137.55	50808249	sink in service room pluged	2005.09.27	2005.10.04	3	GO02
5173	10	2005	PLUMBING	$235.12	50805115	taps not working in the kindergarten w/r	2005.09.22	2005.09.29	3	GO02
5174	10	2005	PLUMBING	$137.55	50808248	bradly not working in boys w/r	2005.09.27	2005.10.04	2	GO02
5175	10	2005	PLUMBING	$583.44	50692409	no water-bradley-girls wr-1st fl	2005.01.14	2005.01.17	1	GO02
5176	10	2005	PLUMBING	$1,206.47	50732368	toilet not woking	2005.04.14	2005.04.19	3	GO08
5177	10	2005	PLUMBING	$132.23	50753389	girls washroom 2nd stall no flush	2005.05.24	2005.05.27	2	GO08
5178	10	2005	PLUMBING	$446.18	50855252	toilet base broken	2005.12.16	2006.01.30	3	GO08
5179	10	2005	PLUMBING	$105.78	50786676	toilet leaking from base boys by office	2005.08.22	2005.08.25	3	GO08
5180	10	2005	PLUMBING	$82.53	50821088	flushometer leaking boys 1st fl w/r	2005.10.19	2005.10.26	3	GO08
5181	10	2005	PLUMBING	$132.23	50786673	toile in the boys secound floor w/r	2005.08.22	2005.08.25	2	GO08
5182	10	2005	PLUMBING	$158.67	50753747	JSHOMETRE NEEDS TO BE REPLAC	2005.05.26	2005.05.31	2	GO08
5183	10	2005	PLUMBING	$185.12	50753388	boys washroom urinals not working	2005.05.24	2005.05.27	2	GO09

Figure 3.5: Sample of Work Orders Related to Plumbing for School 10

Preliminary analysis of the data identified 23 building systems. The statistical details of total work orders and costs related to each systems are shown in Table

3.2. Figure 3.6 shows which systems required the most maintenance work orders in descending order by frequency: interior structure works; heating, ventilating, and air conditioning systems (HVAC); plumbing; electrical systems; electronics systems; and site works.

Table 3.2: Preliminary Analysis of Various Building Systems

Year	System	Brief Description	Total No. of Work Order	Total Cost
2005 and 2006	AHU	Air Handeling Unit	1,111	$374,548
	BAS	Building Automation Systems	495	$123,283
	BOILER	Boiler Systems	932	$434,372
	COMPAIR	Compress Air	523	$83,292
	ELECTR	Electrical Systems	**4,967**	**$1,885,271**
	ELECTRON	Electronics Systems	**3,097**	**$1,053,297**
	ELEVATOR	Elevator	12	$2,339
	EXTSTRUC	External Structure Works	2,072	$783,426
	FLEET	Fleet	9	$1,385
	GLAZING	Glazing Works	516	$140,228
	HVAC	Heating, Ventilating, and Air Conditioning Systems	**6,539**	**$2,597,590**
	INTSTRUC	Interior Structure Works	**7,729**	**$2,811,060**
	LIFTS	Lifts	141	$127,049
	OPSEQMT	Operations Equipment	2,574	$606,372
	PLAYGRND	Play Ground	812	$53,339
	PLUMBING	Plumbing Systems	**6,021**	**$1,954,584**
	POOLS	Pools	349	$197,371
	PORTABLE	Portable	1,441	$141,056
	PUMPS	Pumps	193	$121,786
	REFRIG	Refrigerator	367	$121,679
	SCHEQMT	Schools Equipment	1,534	$384,616
	SIGNAGE	Signage Systems	67	$12,342
	SITEWORK	Site Works	**3,011**	**$1,128,459**
Total		**23 Systems**	**44,512**	**$15,138,744**

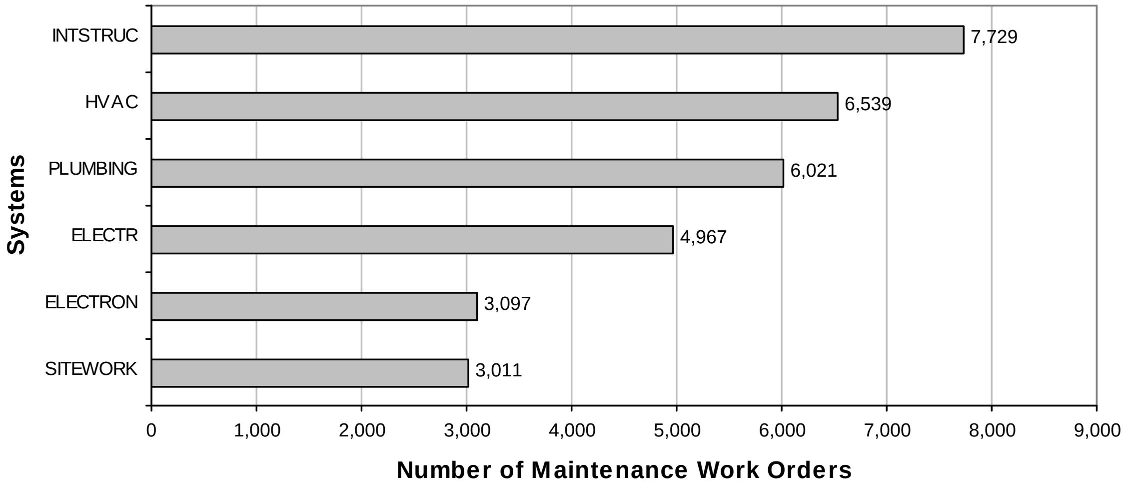


Figure 3.6: The Most Frequent Types of Maintenance Work Orders

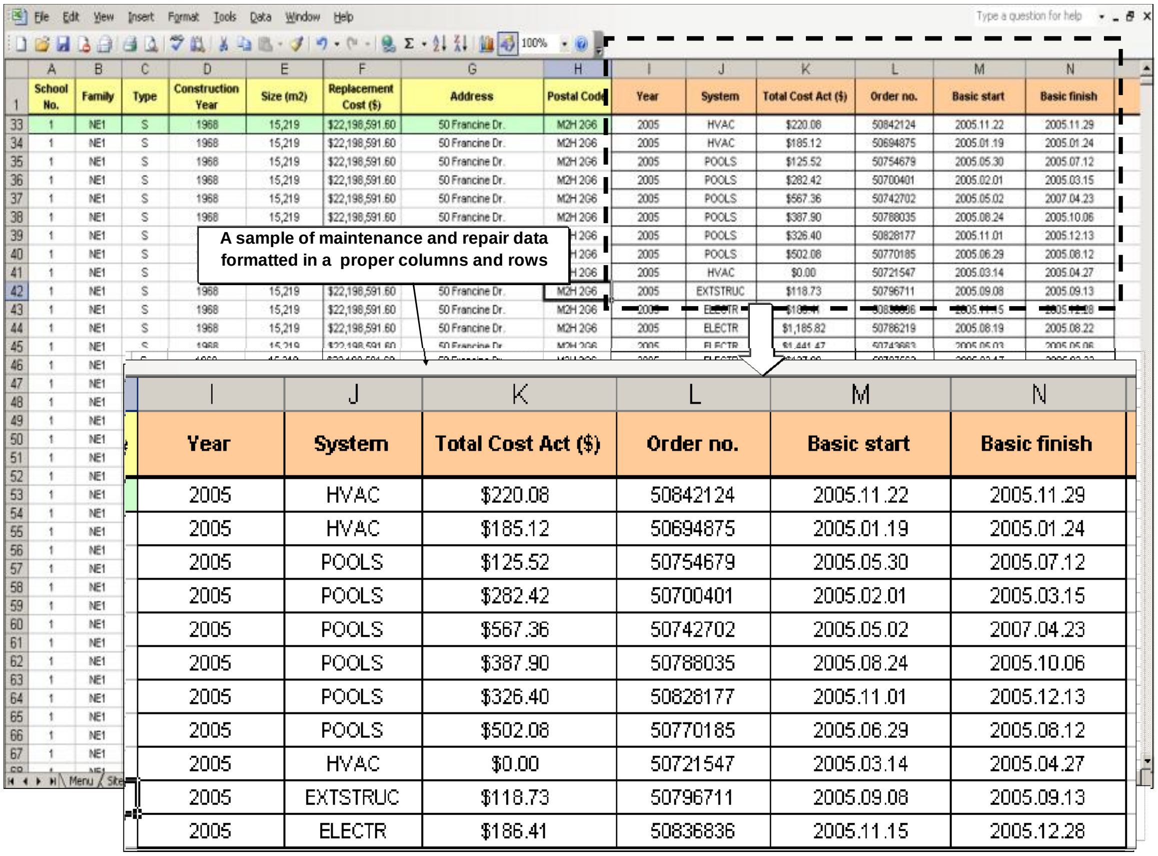
To illustrate the complexity and extent of the data collected, Table 3.3 shows the sample schools within each family, the number of elementary versus secondary schools, and the total work orders with their dollar values.

Table 3.3: Brief Summary of All Data Provided

Year	Family	Type*	No. of Schools	Total No. of Work Orders	Total Cost of Maintenance Jobs
2005 and 2006	NE1	S	4	3,212	$1,220,644
		E	20	7,547	$2,356,848
	NE2	S	3	3,546	$1,197,581
		E	21	7,794	$2,538,071
	NE3	S	3	2,309	$830,203
		E	16	6,889	$2,197,496
	NE4	S	2	2,857	$1,177,801
		E	19	7,488	$2,452,824
	NE6	S	1	1,126	$407,940
		E	_	NA	NA
	NW2	S	_	NA	NA
		E	1	447	$166,091
	SE5	S	_	NA	NA
		E	1	203	$63,720
	SW2	S	_	NA	NA
		E	1	633	$294,139
	SW6	S	1	460	$213,391
		E	_	NA	NA
Total			**93 Schools**	**44,512**	**$15,138,744**

*S=Secondary, E=Elementary

Once the data were collected, the database functions of Excel such as sorting, grouping, automating, and linking are used to prepare the data for statistical analysis. The general data and specific maintenance data for all schools were merged to create a large spreadsheet in order to facilitate the analysis, as shown in Figure 3.7. The left side of the merged spreadsheet shows the general information that relates to the school to which a work order applies . The right side shows the details related to each work order such as the year, system, total cost, order number, and start and finish dates. In this way, the full information about location, cost, duration, and resources was then ready for analysis.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	School No.	Family	Type	Construction Year	Size (m2)	Replacement Cost ($)	Address	Postal Code	Year	System	Total Cost Act ($)	Order no.	Basic start	Basic finish
33	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	HVAC	$220.08	50842124	2005.11.22	2005.11.29
34	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	HVAC	$185.12	50694875	2005.01.19	2005.01.24
35	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	POOLS	$125.52	50754679	2005.05.30	2005.07.12
36	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	POOLS	$282.42	50700401	2005.02.01	2005.03.15
37	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	POOLS	$567.36	50742702	2005.05.02	2007.04.23
38	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	POOLS	$387.90	50788035	2005.08.24	2005.10.06
39	1	NE1	S					H 2G6	2005	POOLS	$326.40	50828177	2005.11.01	2005.12.13
40	1	NE1	S					H 2G6	2005	POOLS	$502.08	50770185	2005.06.29	2005.08.12
41	1	NE1	S					H 2G6	2005	HVAC	$0.00	50721547	2005.03.14	2005.04.27
42	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	EXTSTRUC	$118.73	50796711	2005.09.08	2005.09.13
43	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	ELECTR	$186.41	50836836	2005.11.15	2005.12.28
44	1	NE1	S	1968	15,219	$22,198,591.60	50 Francine Dr.	M2H 2G6	2005	ELECTR	$1,185.82	50786219	2005.08.19	2005.08.22

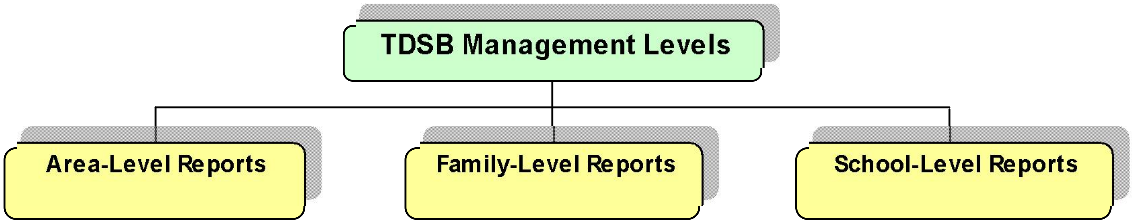
A sample of maintenance and repair data formatted in a proper columns and rows

Figure 3.7: Sample of the Merged Spreadsheet

3.4 Management and Reporting Needs

In general, building assets are characterized and referenced by their geographic locations and spatial relationships. The substantial number of planned maintenance and repair jobs implemented in school components and sub-components take place in scattered geographical locations. Extracting meaningful information from these data therefore requires easy-to-understand reports that facilitate a location-based analysis of trends. Text, charts, and GIS-based reports should be suitable for all levels of decision making in the organization. The ability to store, analyze, and visualize the large amounts of maintenance and repair data is crucial if a system is to provide support so that management can wisely allocate resources, optimize budgets, and avoid conflicts.

The TDSB has three levels of management personnel who are responsible for planning, monitoring, and controlling the maintenance and repair work for all school buildings: upper managers, area managers, and family trades personnel. While all of them need reports that are presented in easy-to-understand formats, each requires information on their reports to satisfy their needs and interests. Upper managers, for instance, are interested in having a big picture of the performance of all areas in term of expenditures and work orders. They are usually seeking reports that show aspects such as the total/average expenditures directed at specific areas by system, year, and/or type. For some decisions, they also need reports that present the number of work orders by system, year, and/or type. On the other hand, area managers are interested in obtaining more specific reports about their school families in order to manage and direct resources. Reports that present several relationships between work orders and performance are helpful for this level of management. Expenditures by family, type, year, and system can play a major role in their ability to efficiently plan and perform their activities. The family trades personnel are responsible for performing preventive maintenance for schools and therefore need to have detailed information about all expenses and work orders. They look for reports that identify overall expenditures and work orders over a specific year. Reports that present comparisons between schools in terms of systems, years, and types and that link them to their demographic characteristics are also important. Figure 3.8 shows a sample of the reporting needs of the different levels of management at the TDSB.



Text Reports	Extract information about all areas/families/schools in terms of total/average expenditures and work orders of all aspects (systems, years, and types)
Chart Reports	Compare between all aspects (systems, years, and types) for all areas/families/schools in terms of total/average costs and work orders.
GIS-based Reports	Visualize data on real-life chart maps and link the data to their demographic characteristics.

Figure 3.8: Reporting Needs of the TDSB Levels of Management

The generated reports can also help decision makers make better decisions about functions that can possibly affect the quality of decisions including resource allocation, quality control, and condition assessment.

3.4.1 Resource Allocation

Planning maintenance and repair jobs for scattered buildings requires the management of multiple resources and schedules. Putting all required data in easy-to-understand reports facilitate analysis and lead to the assignment of the right resources at the right time to the right locations at the right cost. For example, comparing the total expenditures for selected systems in different types of schools in different years can provide insight about the total and average funds required and the approximate number of workers needed.

3.4.2 Quality Control

During the process of analyzing the expenditures and work orders presented in the reports generated, constant demands for specific maintenance jobs at a specific area (number of work orders and the total maintenance costs are high) can bring it to the attention of supervisors so that they can determine whether the items should be considered for replacement .

3.4.3 Condition Assessment

Decisions during the planning process for maintenance and repair jobs depend on many factors, such as current conditions, the total amount spent to maintain the systems, and the performance of the building assets. Failure to accurately predict and assess the current condition may lead to the total failure of an asset and an interruption in service. Furthermore, efficient condition assessment plays a major role in the selection and prioritization of maintenance and repair tasks, which is, in fact, the key to the wise allocation of available resources. Both managers and labourers share the same interest in comprehending the status and performance of the assets for which they are responsible. Analysis and visualization of available data related to the latest costs of implemented jobs can provide a useful insights about the current condition and performance of specific building systems and can thus facilitate the decision -making process. Table 3.4 shows the possible functions that can be supported by analysis o f the reports.

Table 3.4: Possible Functions Supported by Different Reports

Possible Functions	Sample of Analyzed Data
Resource Allocation	Variability of total ependitures in ELECTRIC for NE1 vs NE4. Variability of total expenditures in HVAC vs Plumbing. Variability of total expenditures in Elementary vs Secondary Schools
Quality Control	Total expenditures and work orders in HVAC vs AHU for SW. Total work orders in Elementary vs Secondary for SE1 vs SE6. Total work orders in SITEWORKS for 2005 & 2006.
Condition Assessment	Total work orders in INTSTRUC for all NE4 schools in 2006. Total expenditures in EXSTRUC for School 5, 32, and 45 in 2005. Total expenditures in HVAC for secondary schools in 2005 and 2006.

3.5 Conclusion

This chapter has presented the collection process for a large sample of maintenance and repair data for schools owned by the TDSB. The source of the data, the TDSB, and its levels of management were also introduced. The preliminary analysis of the data and the TDSB’s reporting needs were discussed in order to clarify the nature and significance of the data. Possible functions that can enhance the quality of decisions such as resource allocation, quality control, and condition assessment were described in this chapter.

Chapter 4

Development of a Multi-Level GIS-Based Data Management Model

4.1 Introduction

This chapter introduces the development of a proposed model for storing, editing, and visualizing maintenance and repair data for educational buildings. The model, called Multi-Level GIS-based Data Management Model, is designed to provide useful insights to parties involved in managing and controlling projects related to maintenance and repair. Supporting and facilitating the decision-making process for all levels of management is the main purpose of the designed model. The implementation media of the model is presented in section 4.3, and the design and working mechanism is described in section 4.4.

4.2 Development of a GIS-Based Data Management Model

The model proposed in this research is a GIS-based data management model that allows users to store, edit, manage, and visualize the maintenance and repair data for building assets. The model has the potential to support and enhance decision making during the planning, scheduling, and controlling of maintenance and repair jobs for school buildings. These uses could include the following:

- Enabling efficient collection, management, analysis, and reporting of asset data
- Supporting a more efficient and cost-effective decision-making process by implementing systematic methods to analyze data and optimize the allocation of the maintenance budget according to required performance levels
- Increasing operational efficiency
- Supporting the identification and extraction of new information and trends not readily observable in the original data.

The model has been developed using the Visual Basic for Applications (VBA) programming language of MS Excel. The development of the model has involved substantial programming effort in order to code and integrate the worksheets with one another and with MapPoint in order to provide user-friendly interfaces. This integration plays a major role in facilitating the automation of the proposed model. Basically, the model was developed as a workbook that contains several worksheets, including a main database and user interfaces. While the main database worksheet is designed to store, edit, and manage data, the user interfaces were created and intended to facilitate all functional steps including data mining, reporting and visualization. The development environment for the proposed data visualization model using MS Excel and MapPoint is shown in Figure 4.1.

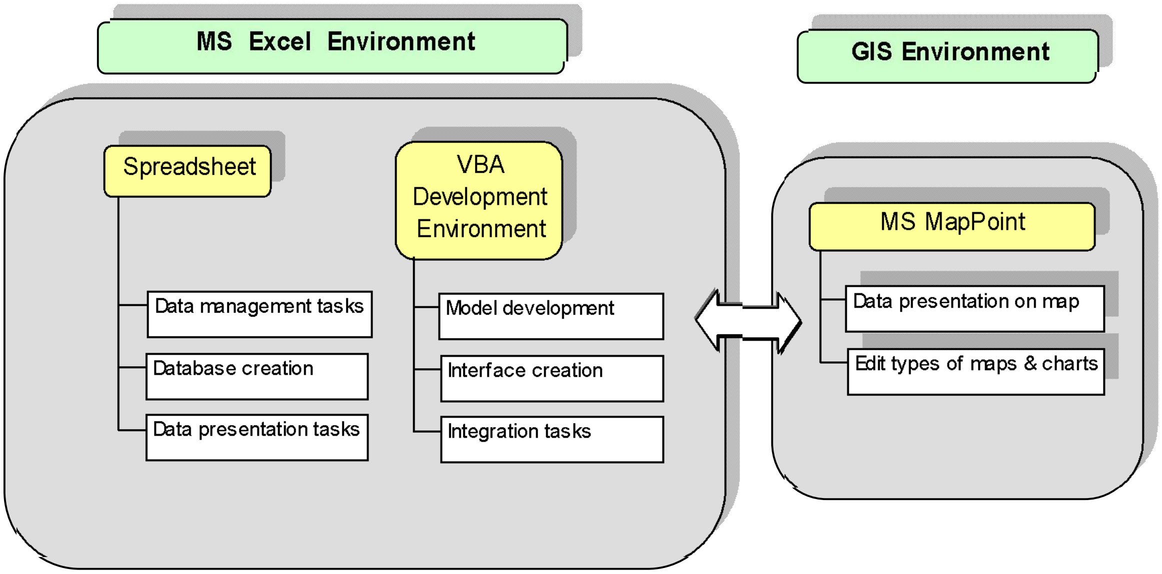


Figure 4.1: The Development Environment for the Proposed Model

Designed to enhance and facilitate the decision-making process during the planning and scheduling phases of maintenance and repair tasks, the model is not intended to provide solid or exact solutions for specific scenarios. Moreover, the designed model allows users to generate different types of reports, including textual and graphical reports that are conveniently suitable for different levels of decision makers including upper manager, area manager, and family trades personnel levels. Reports are generated based on the maintenance and repair data already stored in the database of the model.

The model should therefore have the capability of performing three main tasks: data management, model management, and data presentation. MS Excel, as spreadsheet software, can play a significant role in these three tasks. While worksheets can be used efficiently for data management, VBA has the ability to create complex models and customized buttons within an Excel environment and can also link Excel to other applications. Data presentation can be achieved through the versatile chart wizard tool available in Excel and through the data-mapping wizard provided by external GIS software, such as MS MapPoint.

4.3 Implementation Media

The proposed model lends itself to spreadsheet modeling and GIS software presentation. Each medium has many advantages and powerful features that facilitate the integration and decision-making processes.

4.3.1 Microsoft Excel Spreadsheets

Spreadsheets are among the earliest software innovations that had a profound effect on the widespread use of personal computers. Among their strong features are their intuitive cell-based structure and their simple interface that is easy to use even for a first-time user. Underneath the structure and the interface are a host of powerful and versatile features, from data entry and manipulation to a large number of functions, charts, and word processing capabilities.

The use of spreadsheets can actually make number manipulation easier, more convenient, and more practical. The main advantage that MS Excel offers is that the user can enter volumes of data that can be treated or calculated very quickly and with a very low risk of errors. Once the formulas have been set up, the user also has the option of changing some or all of the data on the spot without having to repeat all of the tedious calculations.

The MS Excel spreadsheet could be considered an indispensable tool for the construction and engineering industry where versatility and productivity are main issues. It offers powerful and versatile features, including the manipulation of data, easy-to-use functions, and word-processing capabilities. Moreover, it can store and create representation of the data such as charts and graphs. In addition, it allows fast dissemination of information and the communication of results to all project participants through networks or online. These features evolve the creation of projections, best-and worst-case scenarios, and time estimates for planning projects. MS Excel also allows the identification of dependencies and time constraints as well as on-time updating of the progress of projects. It can generate plots to determine trends and variable relationships between the project parameters. MS Excel is also used to create schedules by managing the resources and budget of the project and defining project phases, tasks, and other key project parameters.

MS Excel produces a dynamic summary reports through an automated and powerful report generator: the pivot table wizard. Considered the most technologically sophisticated component in MS Excel, a pivot table can help transform rows and columns of numbers and text into a meaningful presentation of the data. Pivot tables enable the user to

- find within the lists the relationships hidden by the details
- display data in the form of subtotals, averages, percentages, etc.
- interact with the created tables by rearranging information and inserting special formulas that perform new calculations
- create automated and dynamic pivot tables by using the VBA programming language and built-in objects

MS Excel's Visual Basic (VB) programming language offers powerful capabilities for users to automate and program the spreadsheets according to their specific requirements. Large amounts of data can be arranged efficiently because a spreadsheet can be linked to other spreadsheets as well as to other Microsoft applications, such as MS MapPoint. VBA facilitates the linkage between MS Excel and other MS applications in order to achieve a more understandable visualization of information. Thus, MS Excel gives the parties involved in a project better access to information, which increases the likelihood of better decisions. Spreadsheets have already been applied successfully in many infrastructure applications such as infrastructure asset management (Hegazy et al., 2004) and planning and cost estimation for highway projects (Hegazy and Ayed, 1998).

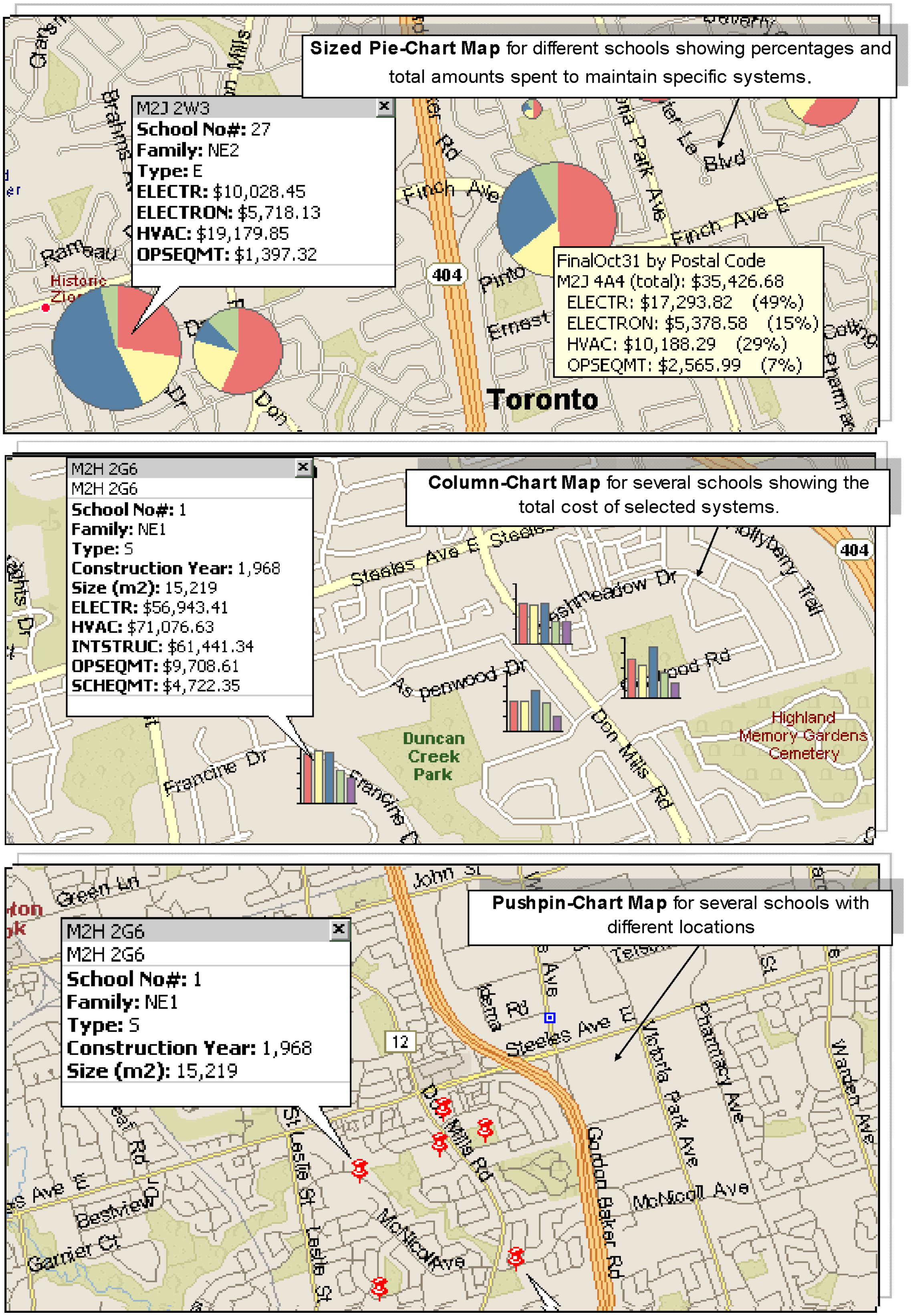
4.3.2 Microsoft MapPoint

Microsoft MapPoint is a simple GIS technology designed to permit the user to visualize, analyze, and display data on maps. Combining powerful mapping and analysis tools with the simplicity of Microsoft Office, MapPoint has been applied to several business sectors to improve investments profits, and solid decisions. MapPoint can provide valuable geographic insights by plotting simply on relevant maps huge amounts of scattered data stored in column-and-row format. MapPoint comes with the highest-quality spatial maps available and includes an extensive variety of integrated maps, that including ones that show political and administrative boundaries (postal codes, counties, Metropolitan areas, states, countries, and more), and extensive transportation networks. MapPoint has already been applied successfully in a variety of applications such as marketing, logistics, businesses, and management. MapPoint was recently presented by Hegazy (2006) for visualizing multiple-site infrastructure.

MapPoint can meet a wide variety of user needs. Since it accepts files from different sources such as MS Excel and Access, it allows users to import, edit, and represent data graphically in several forms, called pie-chart maps, column-chart maps, and pushpin maps. Figure 4.2 shows examples of chart maps provided by MapPoint after some of textual data collected from the TDSB was manually imported. To allow automatic data importing and the generation of chart-maps, MapPoint has been programmed using VBA programming language because it facilitates integration with and the automation of Microsoft Office documents such as MS Excel.

4.4 Design and Development of the Proposed Model

The large sets of data presented in Chapter 3 and the need for different types of reports were considered in the design of a unique model to support the interest of decision makers at different levels. The model was developed based on the capability of the worksheet to store, edit, and manage large amounts of data as well as the dynamic features of the pivot table wizards. To facilitate all processing and automation functions, the model exploited the built-in Excel objects and VBA programming language in the design and creation of the interfaces. Due to the different levels of management at the TDSB, these interfaces are supported with custom dialog boxes and functional buttons to conveniently satisfy all interests and choices. For practicality, the model introduces user interface elements to allow the simple and convenient selection of areas, families, schools, types, years, and systems.



Sized Pie-Chart Map for different schools showing percentages and total amounts spent to maintain specific systems.

M2J 2W3
School No#: 27
Family: NE2
Type: E
ELECTR: $10,028.45
ELECTRON: $5,718.13
HVAC: $19,179.85
OPSEQMT: $1,397.32

FinalOct31 by Postal Code
M2J 4A4 (total): $35,426.68
ELECTR: $17,293.82 (49%)
ELECTRON: $5,378.58 (15%)
HVAC: $10,188.29 (29%)
OPSEQMT: $2,565.99 (7%)

Column-Chart Map for several schools showing the total cost of selected systems.

M2H 2G6
M2H 2G6
School No#: 1
Family: NE1
Type: S
Construction Year: 1,968
Size (m2): 15,219
ELECTR: $56,943.41
HVAC: $71,076.63
INTSTRUC: $61,441.34
OPSEQMT: $9,708.61
SCHEQMT: $4,722.35

Pushpin-Chart Map for several schools with different locations

M2H 2G6
M2H 2G6
School No#: 1
Family: NE1
Type: S
Construction Year: 1,968
Size (m2): 15,219

Figure 4.2: Samples of Chart Maps Provided by MapPoint

The proposed data management model involves two processing steps: data mining, and reporting and visualization (Figure 4.3).

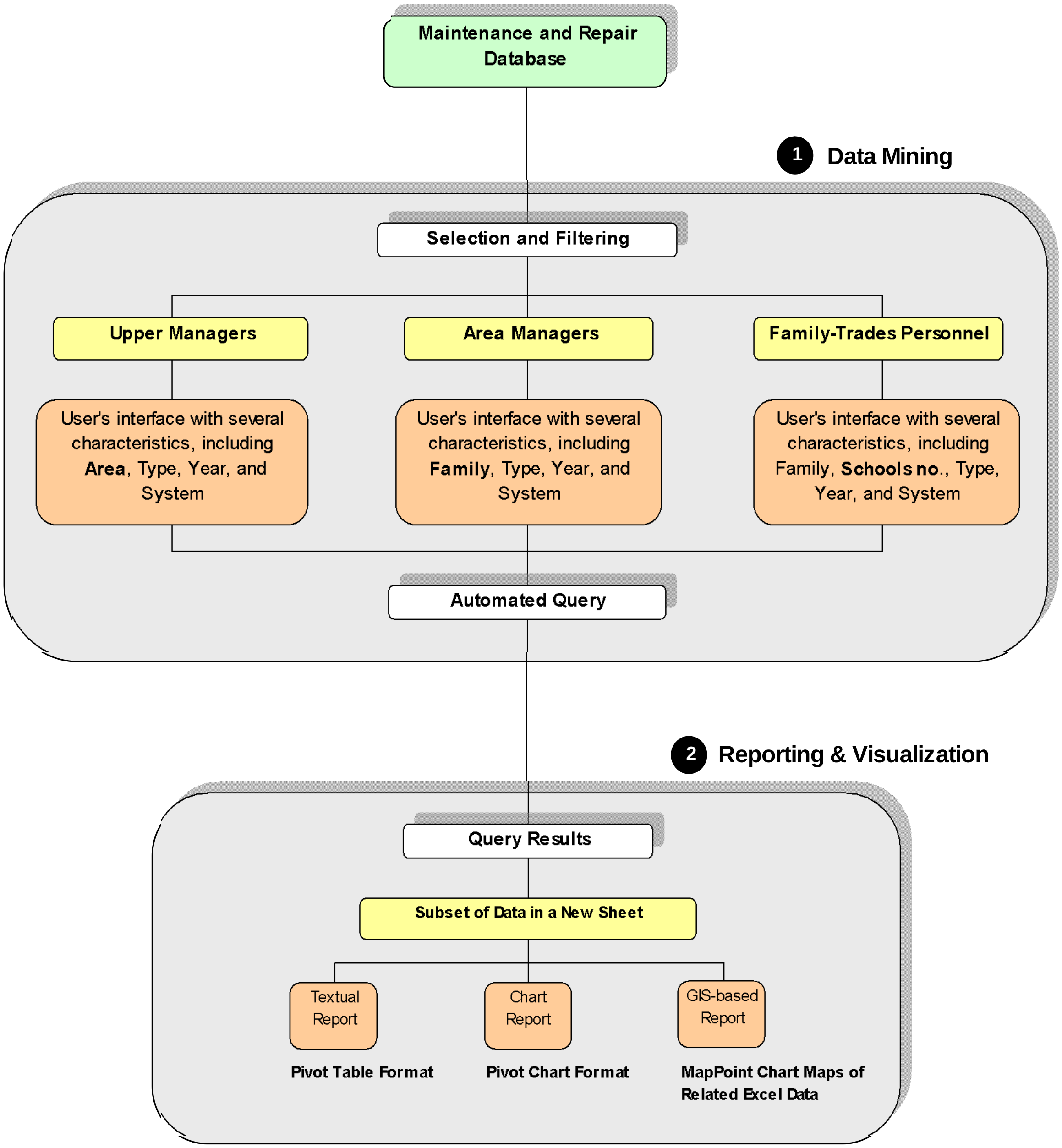


Figure 4.3: Design and Working Mechanism of the Proposed Model

4.4.1 Data Mining

The main idea behind data mining is to facilitate the selection and filtering of data to allow users with different perspectives to “dig” into the data and extract meaningful information. It produces more efficient reports that suit different needs and preferences. In the design of the model, versatile features were added that can select and filter necessary information from the huge data set available. Convenient interfaces were designed and coded to allow the user to select the area, family, school, type, year, and system that correspond to the users’ interests and preferences. For data summarization, optional mathematical functions such as sum, average, and count were added to give flexibility to the desired report structure.

Once all options and filtering are selected, a query is automatically processed through the VBA programming language to produce the subset of data that meet the user’s requirements.

4.4.2 Reporting and Visualization

Once the query results are produced, the user selects the type of report to be produced: textual, chart, or GIS-based (Figure 4.3). Text reports are automated using VBA that links to the pivot table wizard in MS Excel. Charts are also produced on an automated pivot table chart. GIS-based reports, on the other hand, are generated by the automatic exportation of the query results to MS

MapPoint and the activation of the mapping wizard features that produce the desired GIS-based chart-map.

4.5 Conclusion

This chapter has presented the development of the proposed Multi-Level GIS-based Data Management Model for managing, reporting, and enabling the visualization of maintenance and repair data for school buildings. The model conveniently integrates the capabilities of spreadsheet to manage and report data with the GIS software features that enable data to be represented on real-life maps. The VBA programming language was used to facilitate the integration between the two software systems and to automate all functions in the model. The huge sets of data and the different levels of management were considered during the design of the model in order to provide users with useful information and easily produced, relevant reports.

Chapter 5

Model Implementation: A Case Study

5.1 Introduction

This chapter presents the implementation of the Multi-Level GIS-Based Data Management Model that integrates both MS Excel and MS MapPoint. To validate the proposed system and demonstrate its capabilities and efficiency, the real-life maintenance and repair data collected from the TDSB was used to produce reports appropriate for different management levels. More importantly, the model proved capable of inferring hidden information that relates the condition of a component to its maintenance history. This feature demonstrates the important role data management can play in supporting various infrastructure functions and in saving time and money.

5.2 Case Study

The real-life maintenance and repair data for school buildings, as described earlier in Chapter 3, were used as a case study to demonstrate the Multi -Level GIS-Based Data Management Model developed in this research. The data relate to a large number of schools scattered over the northeast (NE) side of the Metropolitan Toronto area. The data were obtained from only 88 schools that belong to NE1, NE2, NE3, and NE4. The data used in the study include a large number of maintenance work orders that cost about $14 million over a two -year period (2005 and 2006) as shown in Table 5.1. Associated with these work orders is a huge amount of information that make it difficult for decision makers to identify hidden trends in the data. Therefore, decision makers would find it enormously helpful to see the full picture of this data through the proposed steps: data mining, automated queries, and reporting and visualization.

Table 5.1: Description of the Data Used in the Study

Year	Area	Family	Type*	No. of Schools	Total No. of Maintenance & Repair Work Orders	Total Cost of Maintenance & Repair Jobs
2005 & 2006	NE	NE1	S	4	3,212	$1,220,644
			E	20	7,547	$2,356,848
		NE2	S	3	3,546	$1,197,581
			E	21	7,794	$2,538,071
		NE3	S	3	2,309	$830,203
			E	16	6,889	$2,197,496
		NE4	S	2	2,857	$1,177,801
			E	19	7,488	$2,452,824
TOTAL			**88 SCHOOLS**		**41,642**	**$13,971,468**

*S=Secondary, E=Elementary

Moreover, the parties involved in different management levels require different views of this data. For instance, the TDSB general maintenance supervisor (upper manager) is interested mainly in a comparison of all amounts spent on specific areas such as northeast (NE) or southwest (SW). An area manager, on the other hand, may be interested only in analyzing the performance of the specific family that he/she is involved in. A family trades personnel is also interested only in monitoring and controlling his/her specific schools and in ensuring the safety and functionality of all of their systems. All parties thus require specific data analysis and reports to support their particular level of management. The proposed model is able to consider these varying needs and combine them in a simple tool that facilitates the tasks faced by decision makers.

5.3 Components and Working Mechanism of the Model

Once the proposed Data Management Model was completely developed, the case study data was input in order to test the model's ability to consider these varying needs and to facilitate decision making. The main components of the model are shown in Figure 5.1. The model consists of easy-to-use interfaces that allow users to link to the reports they require. The main menu interface connects users to three interfaces that represent the different levels of management: upper managers, area managers, and family trades personnel (A, B, and C in Figure 5.1). Each of these interfaces is composed of a number of customized dialog boxes, option buttons, and function buttons that are coded to implement all functions of the model, including data mining, and reporting and visualization.

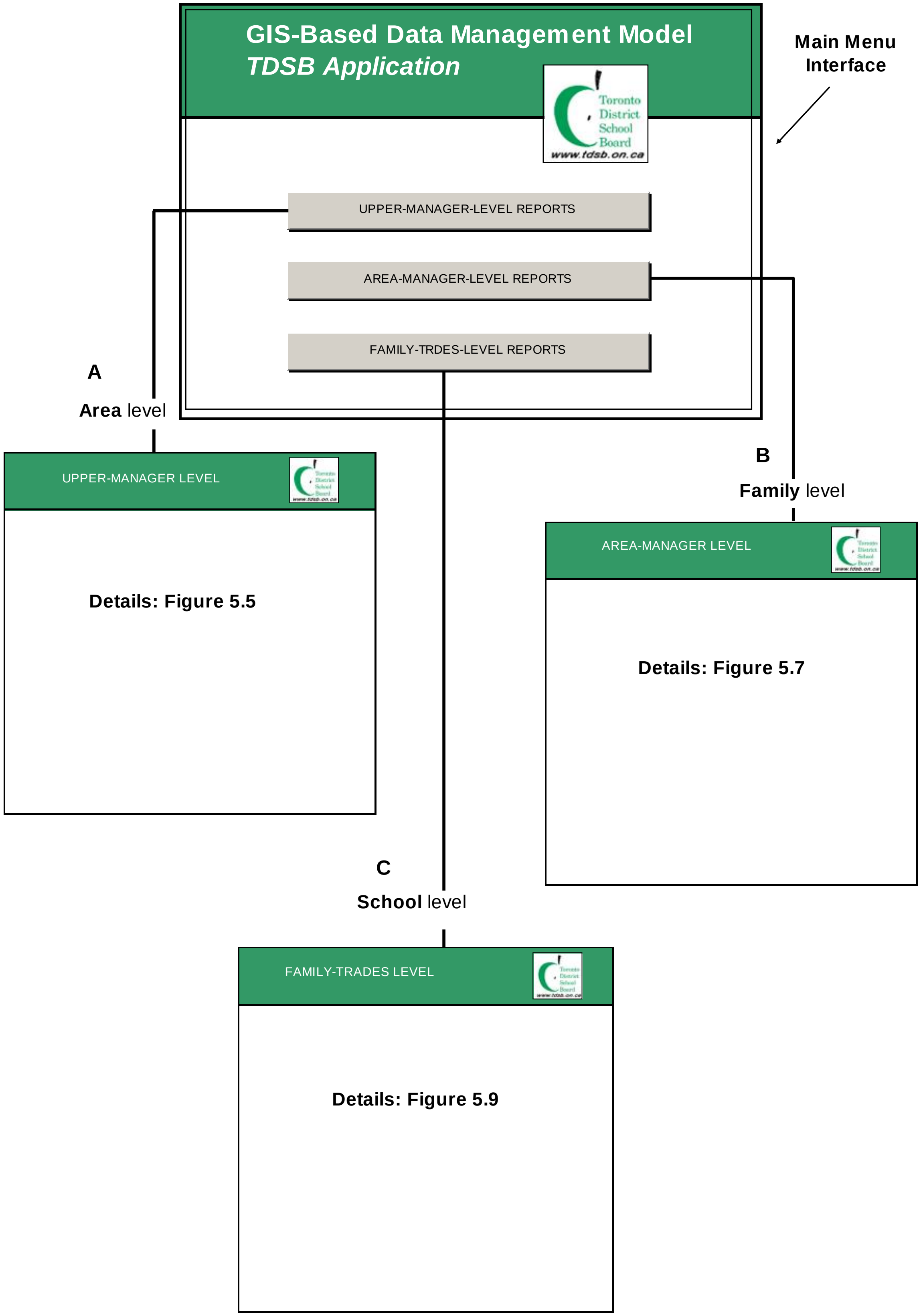


Figure 5.1: Components of the Proposed Model

The customized dialog boxes are coded to be filled with unique options, including area, family, school number, type, year, and system. Option buttons complement the dialog boxes to allow users to choose among three options: total cost, average cost, and number of work orders. The option buttons provide more specific reports generated from the expenditure or the work orders data.

Typically, the working mechanism of the model starts with the selection and filtering steps, i.e., data mining, which are followed by automated queries to activate the reporting and visualization tasks. The automated queries are initiated by a number of function buttons: Prepare Data, Show Textual & Chart Reports, and Show GIS-Based Report. The following steps describe the coded function buttons that automate the model interfaces and generate textual, chart, and GIS-based reports.

5.3.1 Step 1: Prepare Data

This step facilitates the generation of GIS-based reports by sending the selected options (area, family, school number, type, year, and system) to a hidden worksheet where a pre-formatted table is filled so that it can be exported to MapPoint. The table consists of headings consistent with those of the main database and provides full information about the schools selected, including the following (Figure 5.2):

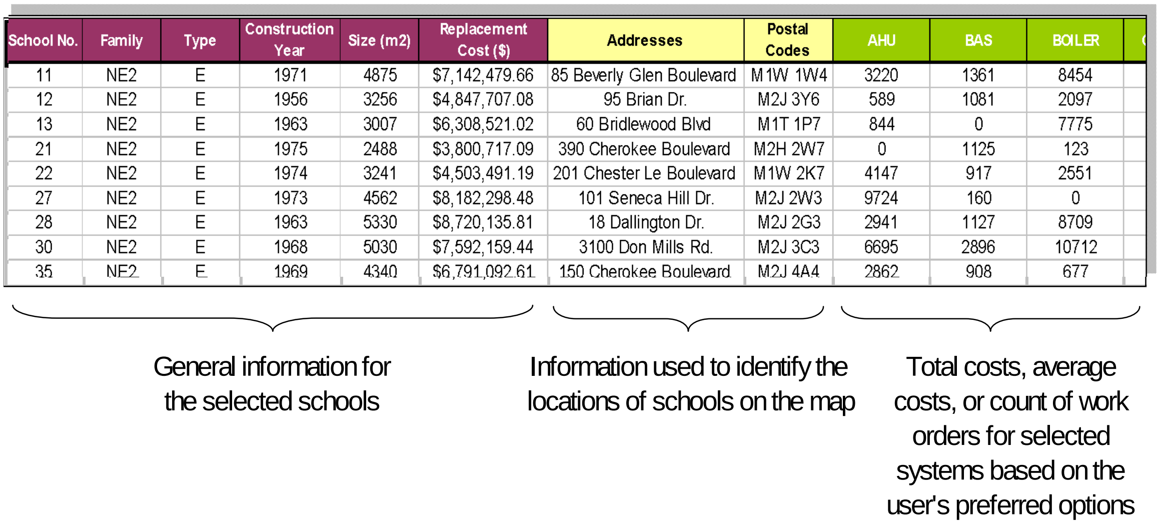
- General information, such as the school number, family, type, construction year, size (m2), and replacement costs

- Information used to identify the location of the schools on the map, such as address and postal code
- Expenditures (total and average costs) or number of work orders for system

All information is extracted using VBA codes that search the entire database to return the specified selections. In addition, the statistical list functions of Excel (DSUM, DAVERAGE, and DCOUNT) are used to produce instantaneous results for specific queries from the main database: total costs, average costs, or number of work orders for selected systems. The roles of these functions in the model can be described as follows:

- DSUM: returns the sum of the maintenance costs for selected systems that meet specific criteria in the main worksheet database
- DAVERAGE: returns the average of the maintenance costs for the selected systems that meet the specific criteria in the main worksheet database.
- DCOUNT: counts the number of maintenance work orders for the selected systems that meet the specified criteria in the main worksheet database.

Figure 5.2 shows an example of a prepared table for a family-trades-level query for several schools. After all data are sent to the table, the table along with data is ready to be exported to MapPoint to be generated as the GIS-based reports.



School No.	Family	Type	Construction Year	Size (m2)	Replacement Cost ($)	Addresses	Postal Codes	AHU	BAS	BOILER
11	NE2	E	1971	4875	$7,142,479.66	85 Beverly Glen Boulevard	M1W 1W4	3220	1361	8454
12	NE2	E	1956	3256	$4,847,707.08	95 Brian Dr.	M2J 3Y6	589	1081	2097
13	NE2	E	1963	3007	$6,308,521.02	60 Bridlewood Blvd	M1T 1P7	844	0	7775
21	NE2	E	1975	2488	$3,800,717.09	390 Cherokee Boulevard	M2H 2W7	0	1125	123
22	NE2	E	1974	3241	$4,503,491.19	201 Chester Le Boulevard	M1W 2K7	4147	917	2551
27	NE2	E	1973	4562	$8,182,298.48	101 Seneca Hill Dr.	M2J 2W3	9724	160	0
28	NE2	E	1963	5330	$8,720,135.81	18 Dallington Dr.	M2J 2G3	2941	1127	8709
30	NE2	E	1968	5030	$7,592,159.44	3100 Don Mills Rd.	M2J 3C3	6695	2896	10712
35	NE2	E	1969	4340	$6,791,092.61	150 Cherokee Boulevard	M2J 4A4	2862	908	677

General information for the selected schools

Information used to identify the locations of schools on the map

Total costs, average costs, or count of work orders for selected systems based on the user's preferred options

Figure 5.2: An Example of Prepared Data for a Family-Trades-Level Query

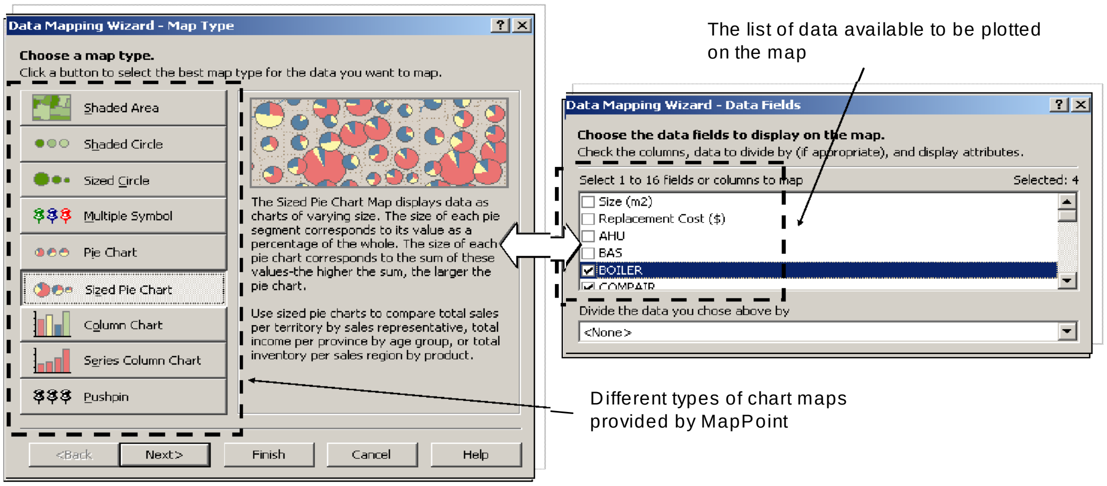
5.3.2 Step 2: Show Textual & Chart Reports

The Show Textual & Chart Reports function button is coded to show a dynamic textual report in a powerful pivot-table format for all selections as well as in a chart format based on the pivot table. This button is the result of a unique VBA code that links between the users' interfaces and the main database. The VBA code sends all selected options to a separate worksheet where a pre-defined pivot table and pivot-table chart are ready to be filled. The final textual and chart reports are generated based primarily on this step.

5.3.3 Step 3: Show GIS-Based Report

For more convenience, the selected options can also be presented on a GIS-based map that provides more visual insight about all the required locations. The data presented on this report is the same data prepared at the step 1 (Prepare Data). The Show GIS-Based Reports button is programmed to link the interfaces and MapPoint, in which a variety of chart maps are available through which different information can be presented. Figure 5.3 shows the main screen of MapPoint where users can choose from the types of maps available and then select the required data fields to be mapped. Figure 5.4 presents a sized pie-chart map of the selected fields. Showing information in this way on a map provides a meaningful way for users to extract the relationships between selected families and the total costs of maintaining them for the last two years (2005 and 2006).

These capabilities and options allow the model to be applied efficiently to the case study. These steps are the backbone of the model and are elaborated on the remainder of this chapter through detailed examples from the case study. While all steps were designed to work in a similar manner, the reports generated at each management level are different with respect to the elements extracted from the database and the contents of the final report.



Choose a map type.
Click a button to select the best map type for the data you want to map.

The Sized Pie Chart Map displays data as charts of varying size. The size of each pie segment corresponds to its value as a percentage of the whole. The size of each pie chart corresponds to the sum of these values-the higher the sum, the larger the pie chart.

Use sized pie charts to compare total sales per territory by sales representative, total income per province by age group, or total inventory per sales region by product.

Choose the data fields to display on the map.
Check the columns, data to divide by (if appropriate), and display attributes.

Select 1 to 16 fields or columns to map Selected: 4

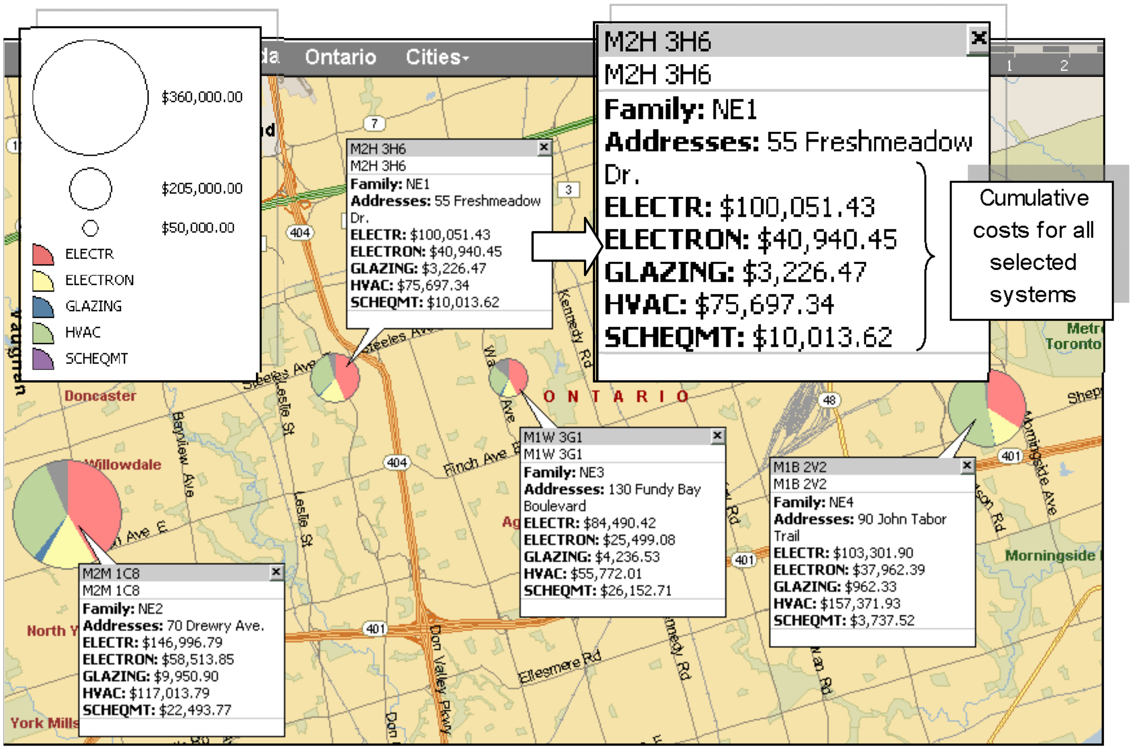
☐ Size (m2)
☐ Replacement Cost ($)
☐ AHU
☐ BAS
☑ BOILER
☑ COMPAIR

Divide the data you chose above by
<None>

The list of data available to be plotted on the map

Different types of chart maps provided by MapPoint

Figure 5.3: Main Screen of Map-Type Selection



M2H 3H6
M2H 3H6
Family: NE1
Addresses: 55 Freshmeadow Dr.
ELECTR: $100,051.43
ELECTRON: $40,940.45
GLAZING: $3,226.47
HVAC: $75,697.34
SCHEQMT: $10,013.62

M2H 3H6
M2H 3H6
Family: NE1
Addresses: 55 Freshmeadow Dr.
ELECTR: $100,051.43
ELECTRON: $40,940.45
GLAZING: $3,226.47
HVAC: $75,697.34
SCHEQMT: $10,013.62

Cumulative costs for all selected systems

M1W 3G1
M1W 3G1
Family: NE3
Addresses: 130 Fundy Bay Boulevard
ELECTR: $84,490.42
ELECTRON: $25,499.08
GLAZING: $4,236.53
HVAC: $55,772.01
SCHEQMT: $26,152.71

M1B 2V2
M1B 2V2
Family: NE4
Addresses: 90 John Tabor Trail
ELECTR: $103,301.90
ELECTRON: $37,962.39
GLAZING: $962.33
HVAC: $157,371.93
SCHEQMT: $3,737.52

M2M 1C8
M2M 1C8
Family: NE2
Addresses: 70 Drewry Ave.
ELECTR: $146,996.79
ELECTRON: $58,513.85
GLAZING: $9,950.90
HVAC: $117,013.79
SCHEQMT: $22,493.77

Figure 5.4: Sized Pie-Chart Map for Selected Families and Systems

5.4 Experimenting with the Model

The following subsections describe the experiments with the developed model to show its ability to manage huge sets of data and to generate different types of reports for different management levels.

5.4.1 Upper-Manager-Level Reports

Upper managers frequently require an overview of comparative performance among all the school areas and need to analyze different aspects of the performance. Upper-manager-level reports therefore provide the type of information they require. Upper managers would use the Upper-Manager-Level Reports option (Main Menu Interface in Figure 5.1). The user is directed to the specific interface that relates to the area level (A in Figure 5.1). The user then makes a number of selections using the customized dialog boxes and option buttons to define their reporting preferences, as shown in Figure 5.5. In this example, the northeast (NE) area is selected for both types of schools (elementary and secondary) in both years (2005 and 2006), and for three systems (ELECTR, ELECTRON, and HVAC). The Sum of Costs option button is also checked as the manager’s measure of the maintenance performance for the selected systems. The function buttons are then used to generate the associated reports.

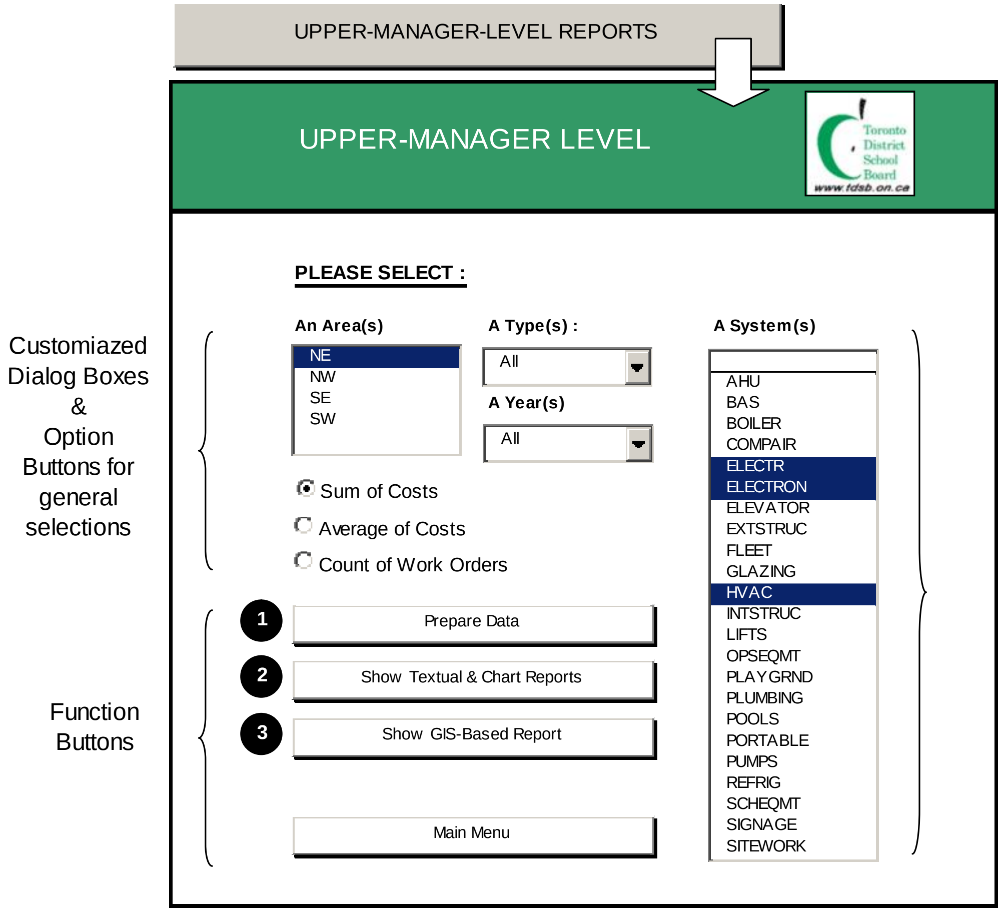
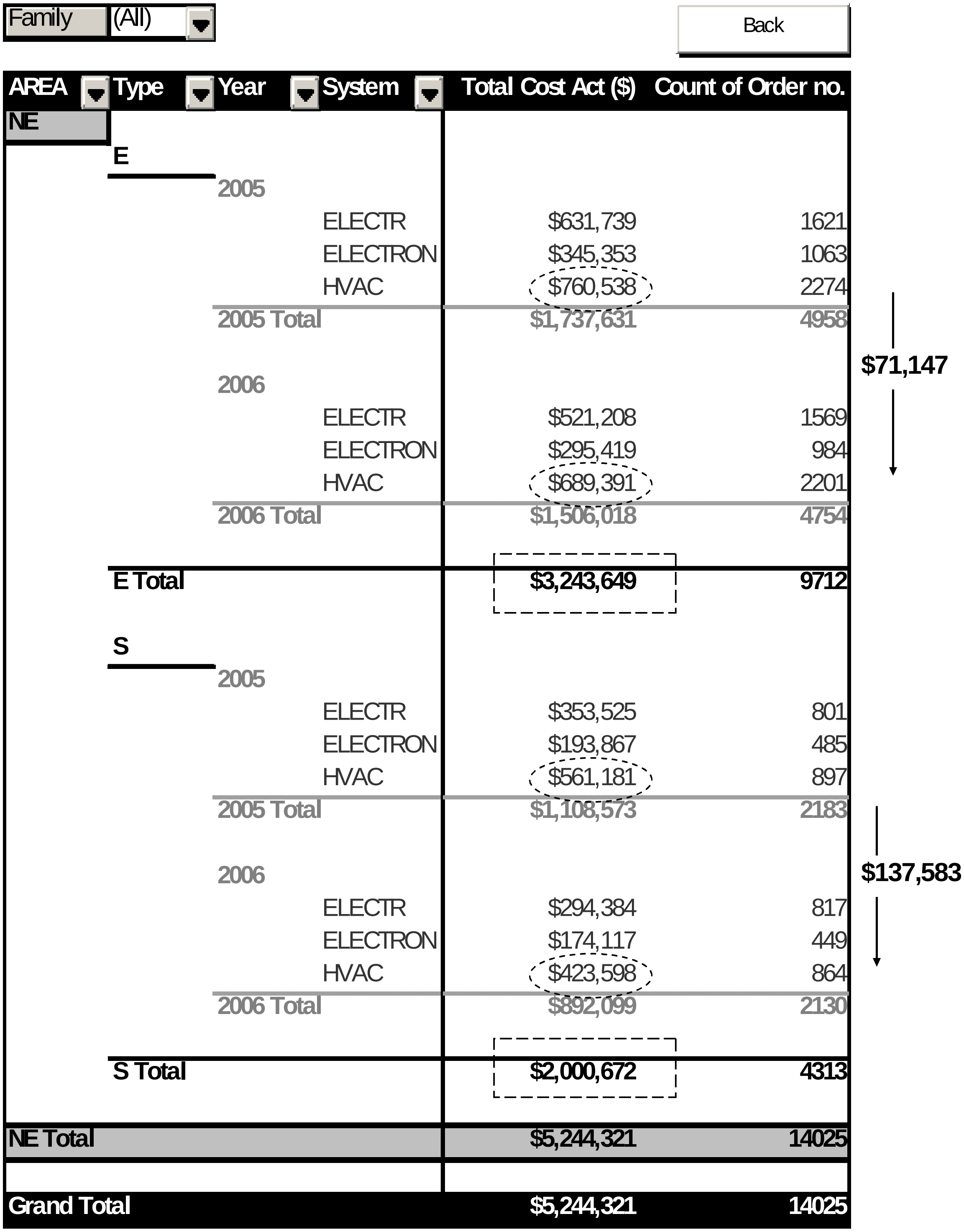


Figure 5.5: Interface for Upper-Manager Level

The textual and chart reports associated with the upper-manager level are shown in Figures 5.6a and 5.6b, respectively. The different types of report allow the upper manager to compare the systems simultaneously. For example, it can be seen that the total expenditures for maintaining and repairing the heating, ventilating, and air conditioning systems (HVAC) in the elementary schools have dropped to $689,391 in 2006, as compared to the $760,538 spent in 2005, a significant reduction of $71,147. Similarly, maintaining and repairing the HVAC systems in the secondary schools cost $561,181 in 2005 and only $423,598 in 2006, with a significant reduction in expenditures ($137,583). Knowledge of these considerable reductions might help the decision maker with future planning. From Figures 5.6a and 5.6b interesting conclusions can be drawn:

- The overall expenditures for HVAC systems in secondary schools are lower than for those in elementary schools as are total maintenance expenditures.
- The condition of the HVAC systems in both the elementary and secondary schools improved in 2006 (the lower the total costs, the better the condition, since the budget did not change from 2005 to 2006).
- The significant reductions in the total costs may save resources that can be used for other deteriorating systems in other areas (optimizing resource allocation).



Family (All)

AREA	Type	Year	System	Total Cost Act ($)	Count of Order no.
NE					
	E				
		2005			
			ELECTR	$631,739	1621
			ELECTRON	$345,353	1063
			HVAC	$760,538	2274
		2005 Total		$1,737,631	4958
		2006			
			ELECTR	$521,208	1569
			ELECTRON	$295,419	984
			HVAC	$689,391	2201
		2006 Total		$1,506,018	4754
	E Total			$3,243,649	9712
	S				
		2005			
			ELECTR	$353,525	801
			ELECTRON	$193,867	485
			HVAC	$561,181	897
		2005 Total		$1,108,573	2183
		2006			
			ELECTR	$294,384	817
			ELECTRON	$174,117	449
			HVAC	$423,598	864
		2006 Total		$892,099	2130
	S Total			$2,000,672	4313
NE Total				$5,244,321	14025
Grand Total				$5,244,321	14025

$71,147

$137,583

Figure 5.6a: A Textual Report Generated at the Upper-Manager Level

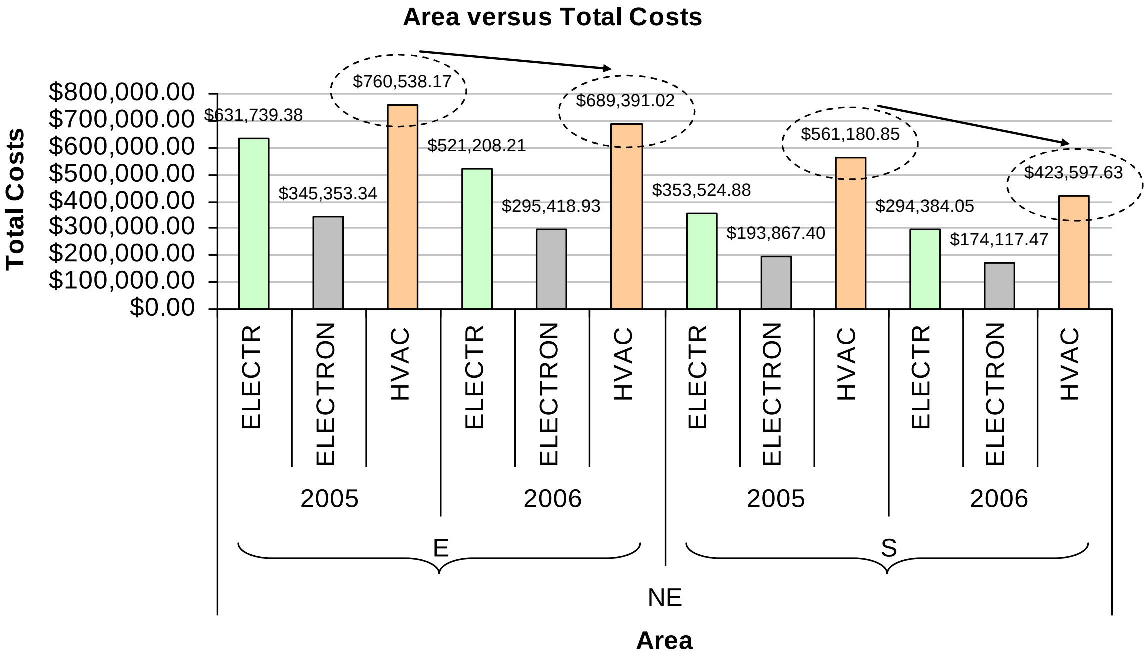
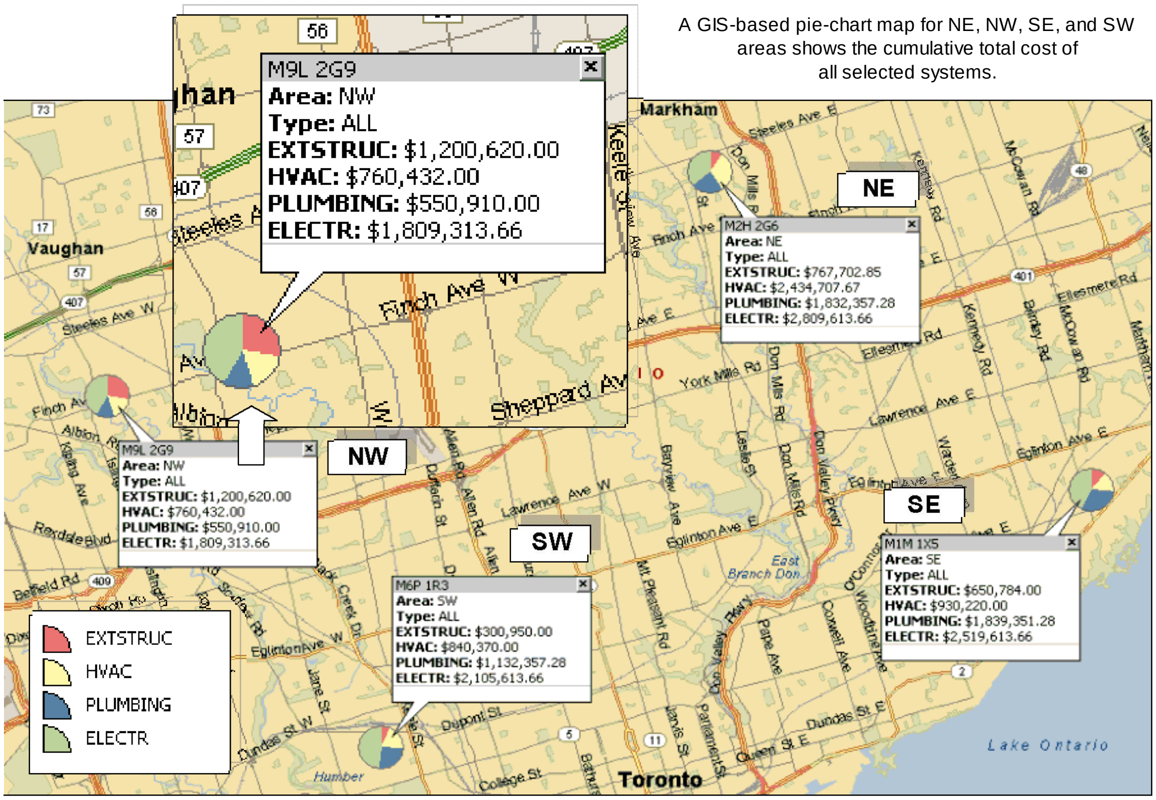


Figure 5.6b: A Chart Report Generated at the Upper-Manager Level

It should be noted that the existing data relates to one area only: NE. To demonstrate the added benefit of GIS-based reports at this level of management, an assumed set of data related to several areas was used to generate the report The resulting report can thus compare the performance of several systems in four areas: NE, NW, SE, and SW (Figure 5.6c).

Such GIS-based reports can play a major role in linking the schools' maintenance and repair data to the specific demographic characteristics of each area. For example, the highest total costs for exterior structure systems (EXTSTRUC) were in the NW area, as shown in Figure 5.6c, which may mean that this area has demographic features that lead to these high costs, such as a high-density neighborhood or a high level of recorded vandalism.



A GIS-based pie-chart map for NE, NW, SE, and SW areas shows the cumulative total cost of all selected systems.

M9L 2G9
Area: NW
Type: ALL
EXTSTRUC: $1,200,620.00
HVAC: $760,432.00
PLUMBING: $550,910.00
ELECTR: $1,809,313.66

M9L 2G9
Area: NW
Type: ALL
EXTSTRUC: $1,200,620.00
HVAC: $760,432.00
PLUMBING: $550,910.00
ELECTR: $1,809,313.66

M2H 2G6
Area: NE
Type: ALL
EXTSTRUC: $767,702.85
HVAC: $2,434,707.67
PLUMBING: $1,832,357.28
ELECTR: $2,809,613.66

M6P 1R3
Area: SW
Type: ALL
EXTSTRUC: $300,950.00
HVAC: $840,370.00
PLUMBING: $1,132,357.28
ELECTR: $2,105,613.66

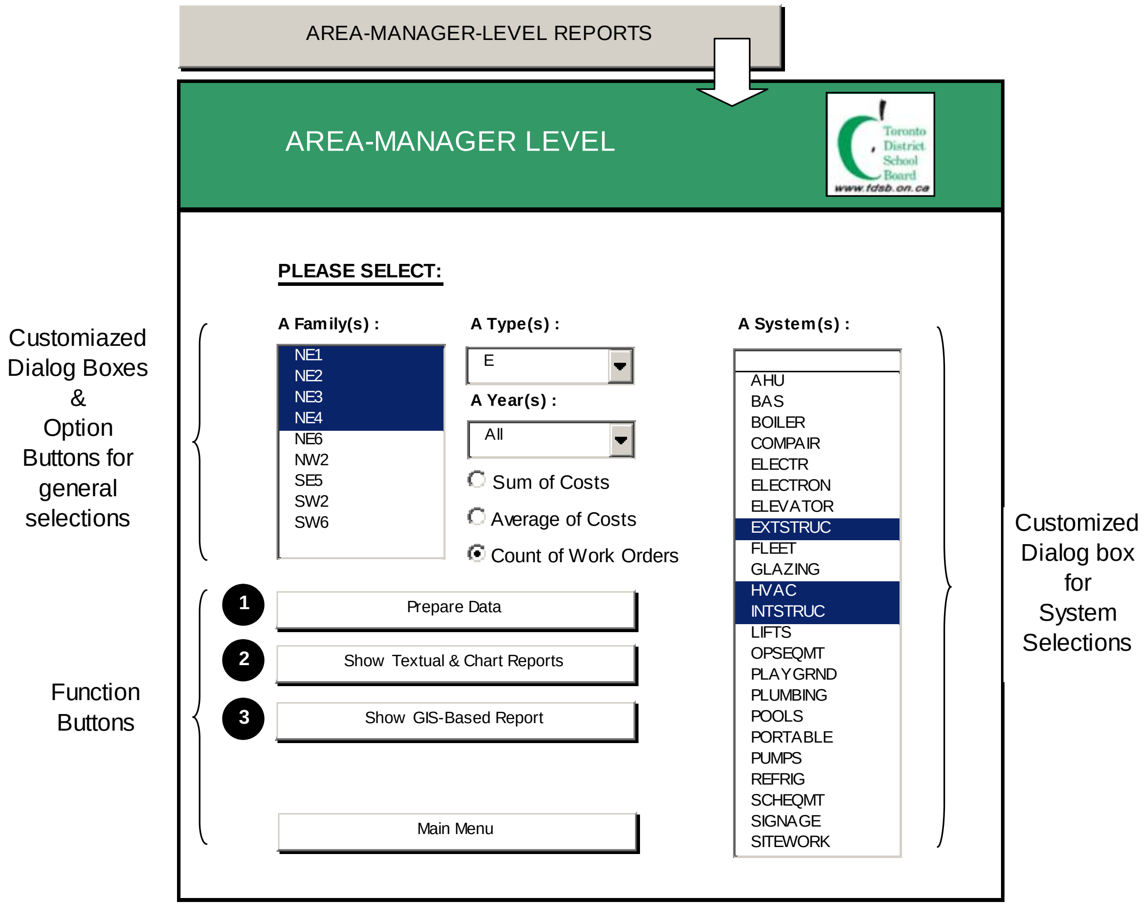
M1M 1X5
Area: SE
Type: ALL
EXTSTRUC: $650,784.00
HVAC: $930,220.00
PLUMBING: $1,839,351.28
ELECTR: $2,519,613.66

Figure 5.6c: A GIS-Based Report Generated at the Upper-Manager Level

5.4.2 Area-Manager-Level Reports

Clicking on the Area-Manager-Level Reports button (Main Menu Interface in Figure 5.1), transfers the user to the Area-Manager-level interface (B in Figure 5.1) that allow users to select several options that satisfy the managements of the area managers (Figure 5.7). For the purposes of the case study, the selections at this stage were as follows:

- Family: NE1, NE2, NE3, and NE4
- Type: Elementary Schools
- Year: 2005 and 2006
- Systems: EXTSTRUC, HVAC, and INTSTRUC



A Family(s) : NE1, NE2, NE3, NE4

A Type(s) : E

A Year(s) : All

○ Sum of Costs

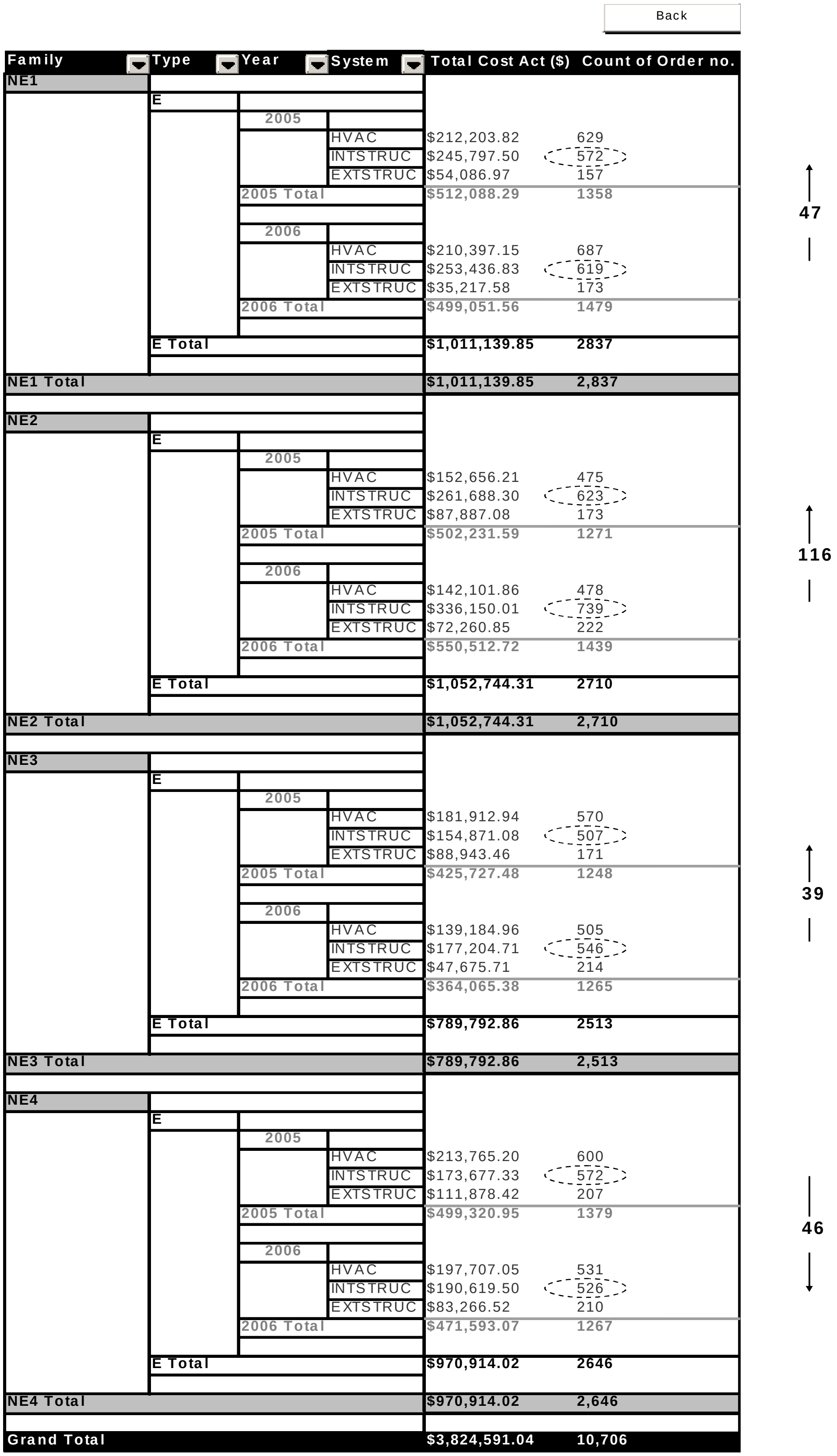
○ Average of Costs

● Count of Work Orders

A System(s) : EXTSTRUC, HVAC, INTSTRUC

Figure 5.7: Interface for Area-Manager Level

To test the different capabilities of the model, the user was assumed to have selected the Count of Work Orders option button at this level of report. Once all selections are made, the model is ready to proceed with the typical functional steps. The coded Show Textual & Chart Reports button is used to create the textual and chart reports, while the GIS-based report is dynamically produced when the Show GIS-Based Reports button is activated. A full representation of all the reports generated is shown in Figures 5.8a, 5.8b, and 5.8c.



Family	Type	Year	System	Total Cost Act ($)	Count of Order no.
NE1					
	E				
		2005			
			HVAC	$212,203.82	629
			INTSTRUC	$245,797.50	572
			EXTSTRUC	$54,086.97	157
		2005 Total		$512,088.29	1358
		2006			
			HVAC	$210,397.15	687
			INTSTRUC	$253,436.83	619
			EXTSTRUC	$35,217.58	173
		2006 Total		$499,051.56	1479
	E Total			$1,011,139.85	2837
NE1 Total				$1,011,139.85	2,837
NE2					
	E				
		2005			
			HVAC	$152,656.21	475
			INTSTRUC	$261,688.30	623
			EXTSTRUC	$87,887.08	173
		2005 Total		$502,231.59	1271
		2006			
			HVAC	$142,101.86	478
			INTSTRUC	$336,150.01	739
			EXTSTRUC	$72,260.85	222
		2006 Total		$550,512.72	1439
	E Total			$1,052,744.31	2710
NE2 Total				$1,052,744.31	2,710
NE3					
	E				
		2005			
			HVAC	$181,912.94	570
			INTSTRUC	$154,871.08	507
			EXTSTRUC	$88,943.46	171
		2005 Total		$425,727.48	1248
		2006			
			HVAC	$139,184.96	505
			INTSTRUC	$177,204.71	546
			EXTSTRUC	$47,675.71	214
		2006 Total		$364,065.38	1265
	E Total			$789,792.86	2513
NE3 Total				$789,792.86	2,513
NE4					
	E				
		2005			
			HVAC	$213,765.20	600
			INTSTRUC	$173,677.33	572
			EXTSTRUC	$111,878.42	207
		2005 Total		$499,320.95	1379
		2006			
			HVAC	$197,707.05	531
			INTSTRUC	$190,619.50	526
			EXTSTRUC	$83,266.52	210
		2006 Total		$471,593.07	1267
	E Total			$970,914.02	2646
NE4 Total				$970,914.02	2,646
Grand Total				$3,824,591.04	10,706

Figure 5.8a: A Textual Report Generated at the Area-Manager Level

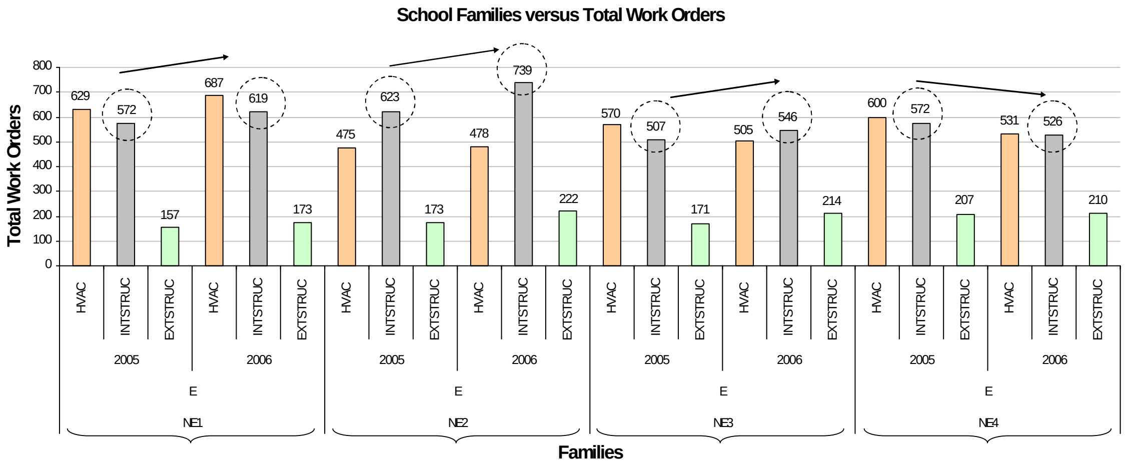
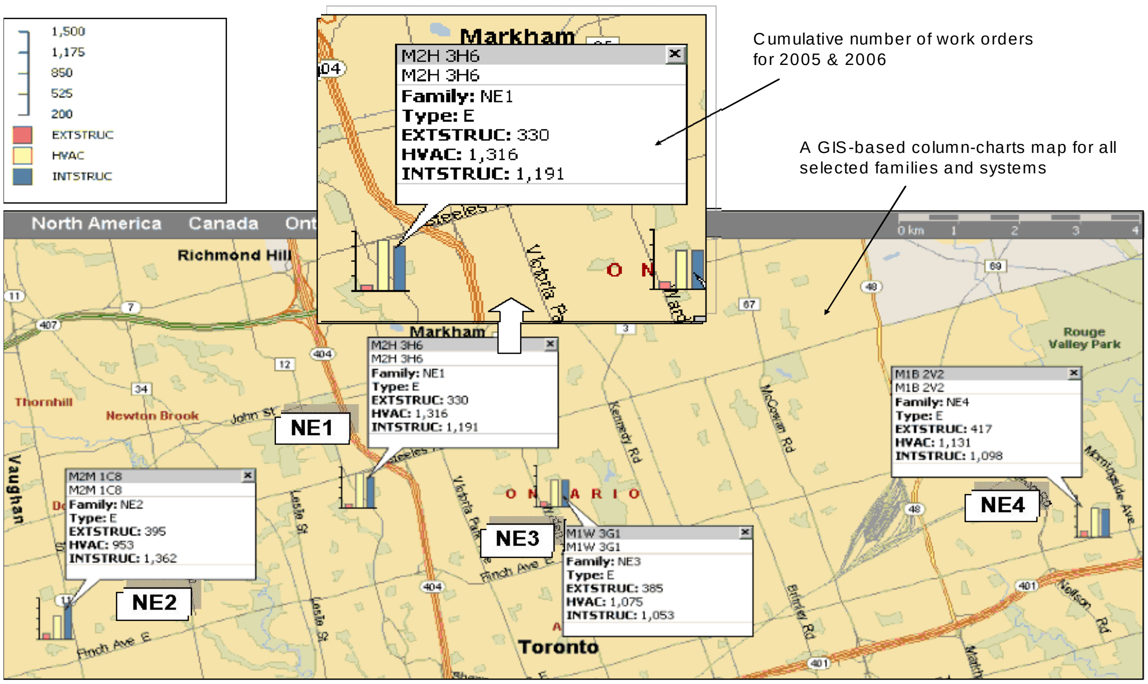


Figure 5.8b: A Chart Report Generated at the Area-Manager Level



Cumulative number of work orders for 2005 & 2006

A GIS-based column-charts map for all selected families and systems

M2H 3H6
M2H 3H6
Family: NE1
Type: E
EXTSTRUC: 330
HVAC: 1,316
INTSTRUC: 1,191

M2H 3H6
M2H 3H6
Family: NE1
Type: E
EXTSTRUC: 330
HVAC: 1,316
INTSTRUC: 1,191

M2M 1C8
M2M 1C8
Family: NE2
Type: E
EXTSTRUC: 395
HVAC: 953
INTSTRUC: 1,362

M1W 3G1
M1W 3G1
Family: NE3
Type: E
EXTSTRUC: 385
HVAC: 1,075
INTSTRUC: 1,053

M1B 2V2
M1B 2V2
Family: NE4
Type: E
EXTSTRUC: 417
HVAC: 1,131
INTSTRUC: 1,098

Figure 5.8c: A GIS-Based Report Generated at the Area-Manager Level

As can be seen in Figures 5.8a and 5 .8b, the generated reports can help identify several underlying relationships. For instance, the work orders for the interior structure (INTSTRUC) increased slightly in NE1, NE2, and NE3, while decreasing in NE4. Moreover, there were 572 work orders in NE1 in 2005, costing about $245,797; in 2006 they increased to 619 (47 extra work orders), costing about $253,436 ($7,639 more). Similarly, NE2 and NE3 also show an increase in the number of completed work orders of 116 and 39, respectively, with corresponding increases in their total costs. The work orders for NE4, on the other hand, decreased by 46 from 572 in 2005 to 526 in 2006. This decrease is associated with an increase in the total costs from $173,677 in 2005 to $190,619 in 2006. This inconsistent relationship between the work orders and total costs may draw attention to these families. A more efficient evaluation of maintenance work may be required for a more accurate condition assessment of deteriorating components. Some conclusions can be drawn from the textual and chart reports (Figure 5.8a and 5.8b):

- The overall work orders of INTSTRUC systems in NE1, NE2, and NE3 are increasing, which could mean that INTSTRUC systems are deteriorating.
- The condition of the INTSTRUC systems in NE4 improved in 2006 (the lower the total number of work orders, the better the condition).

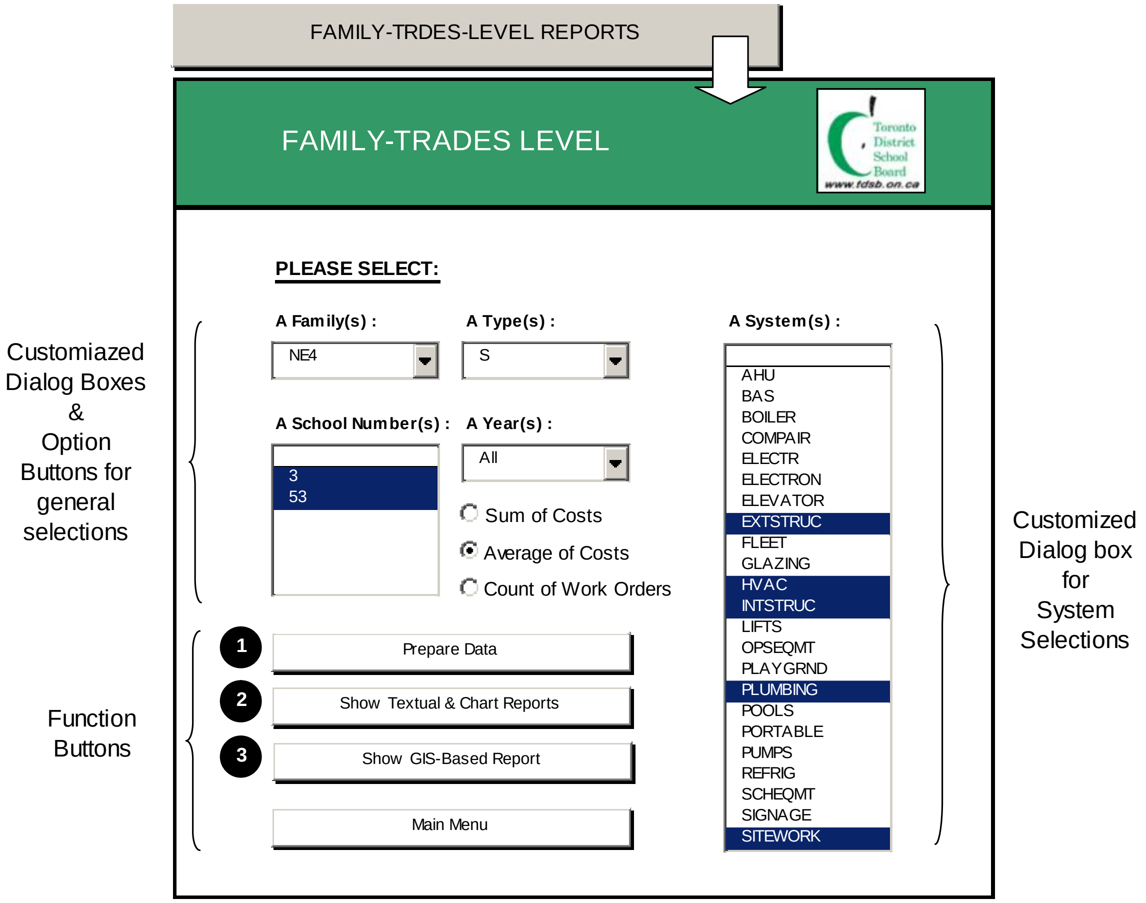
Likewise, from Figure 5.8c, the decision maker can use the GIS -based report to visually show bars to represent the cumulative total for the systems selected for each family, in this case the EXTSTRUC, HVAC, and INTSTRUC. The report indicates that the cumulative number of work orders at NE1 for EXSTRUC, HVAC, and INTSTRUC are 330, 1,316, and 1,191, respectively. It shows that the highest number of work orders directed at the EXSTRUC systems were at NE4

(417 work orders) and also that the HVAC systems at NE1 received 1,316 work orders, significantly higher than other families. NE2, on the other hand, at 1,362, had the highest number of work orders for the INTSTRUC systems. Coupled with knowledge of the demographic characteristics of each family, these comparative reports can help the decision makers find causes of the differences in the numbers of maintenance work orders and, accordingly, can influence repair decisions in the future.

5.4.3 Family-Trades-Level Reports

The family-trades level of reports leads to more comprehensible information about individual schools and the performance of their systems in terms of total costs, average costs, and total work orders. As with the other levels, activating the Family-Trades-Level Reports button (Main Menu Interface in Figure 5.1), transfers the user to the caretaker-level interface (C in Figure 5.1) where all selections are made and filtering tasks are activated. The reports generated at this stage give users more insight and information about each school in a family and allow the family trades personnel to analyze trends. Figure 5.9 shows the selections made to test this level of reports, which can be listed as follows:

- Family: NE4
- Type: Secondary Schools
- School Number: 3 and 53
- Year: 2005 and 2006
- Systems: EXTSTRUC, HVAC, INTSTRUC, PLUMBING, and SITEWORK



FAMILY-TRDES-LEVEL REPORTS

FAMILY-TRADES LEVEL

PLEASE SELECT:

A Family(s) : NE4

A Type(s) : S

A School Number(s) : 3, 53

A Year(s) : All

○ Sum of Costs

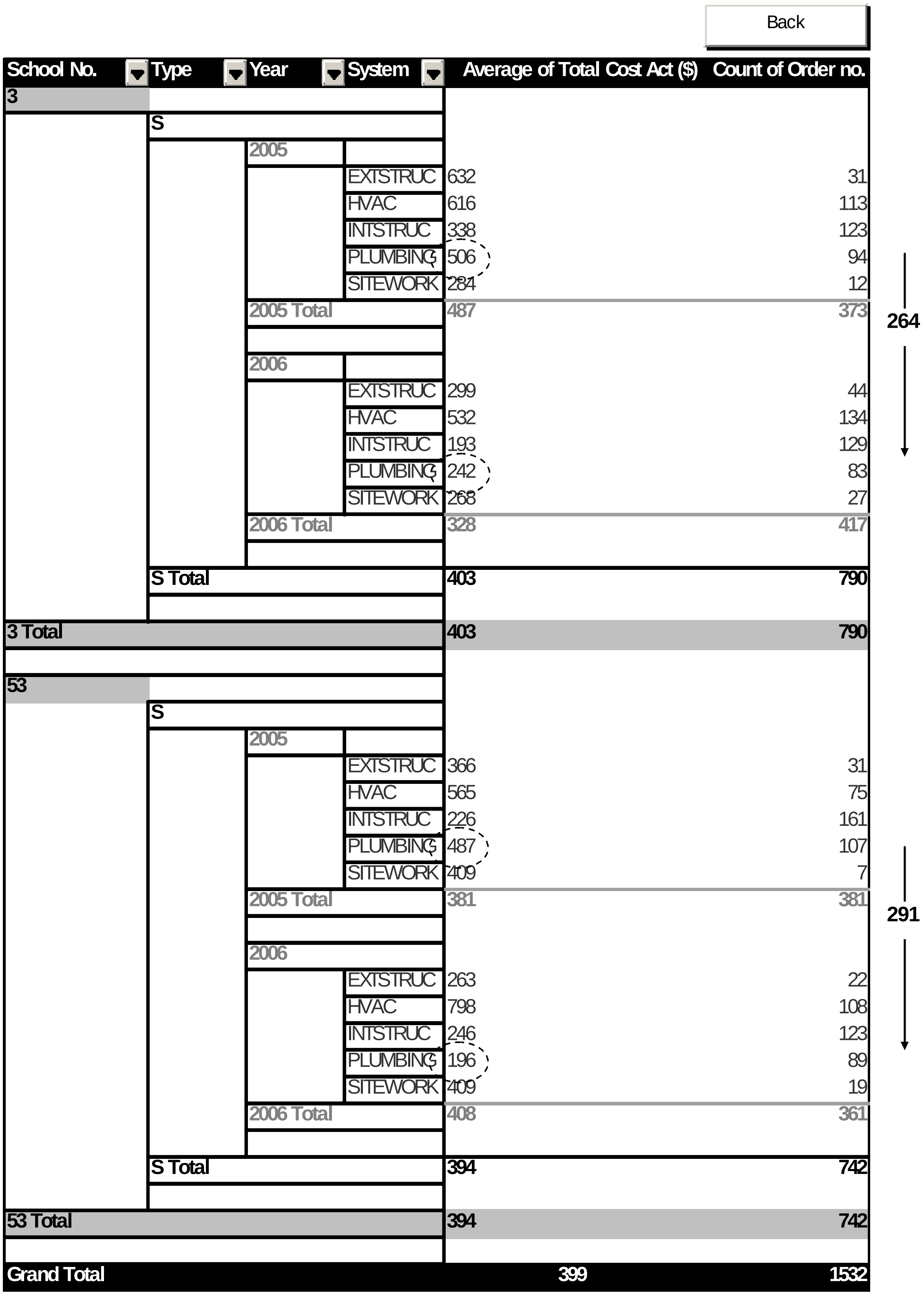
● Average of Costs

○ Count of Work Orders

A System(s) : AHU, BAS, BOILER, COMPAIR, ELECTR, ELECTRON, ELEVATOR, EXTSTRUC, FLEET, GLAZING, HVAC, INTSTRUC, LIFTS, OPSEQMT, PLAYGRND, PLUMBING, POOLS, PORTABLE, PUMPS, REFRIG, SCHEQMT, SIGNAGE, SITEWORK (selected: EXTSTRUC, HVAC, INTSTRUC, PLUMBING, SITEWORK)

Figure 5.9: Interface for Family-Trades Level

Since the function for Total of Costs and Count of Work Orders have already been tested, Average of Costs option button is selected at this level of reports in order to verify several advantages of the model. As with the previous levels of reports, function buttons are clicked to activate all the automation steps that will produce the dynamic reports: text-based, chart-based and, GIS-based (Figures 5.10a, 5.10b, 5.10c, respectively).



School No.	Type	Year	System	Average of Total Cost Act ($)	Count of Order no.
3					
	S				
		2005			
			EXTSTRUC	632	31
			HVAC	616	113
			INTSTRUC	338	123
			PLUMBING	506	94
			SITEWORK	284	12
		2005 Total		487	373
		2006			
			EXTSTRUC	299	44
			HVAC	532	134
			INTSTRUC	193	129
			PLUMBING	242	83
			SITEWORK	268	27
		2006 Total		328	417
	S Total			403	790
3 Total				403	790
53					
	S				
		2005			
			EXTSTRUC	366	31
			HVAC	565	75
			INTSTRUC	226	161
			PLUMBING	487	107
			SITEWORK	409	7
		2005 Total		381	381
		2006			
			EXTSTRUC	263	22
			HVAC	798	108
			INTSTRUC	246	123
			PLUMBING	196	89
			SITEWORK	409	19
		2006 Total		408	361
	S Total			394	742
53 Total				394	742
Grand Total				399	1532

Figure 5.10a: A Textual Report Generated at the Family-Trades Level

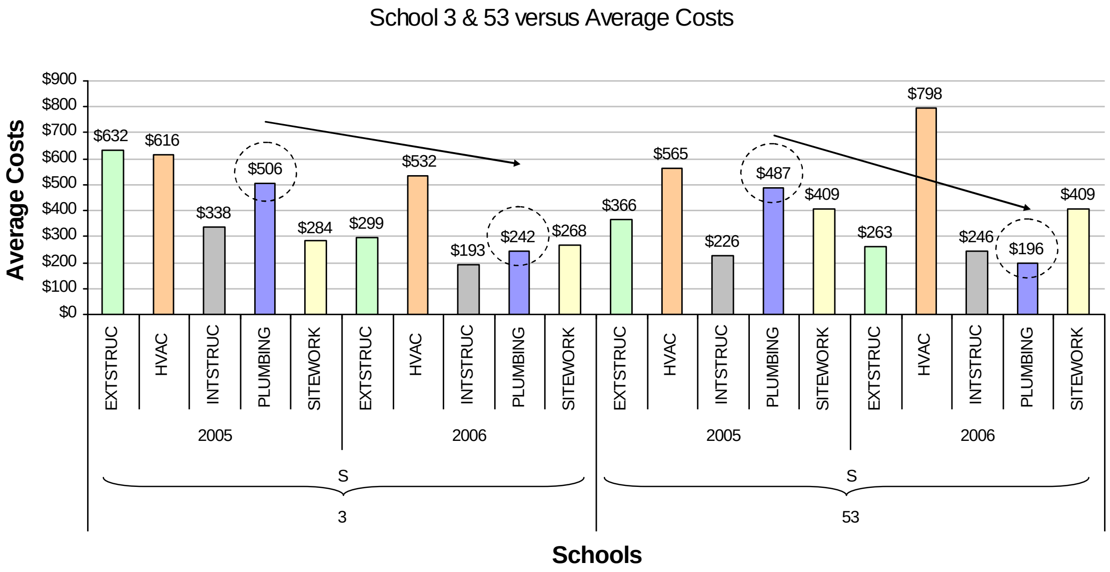
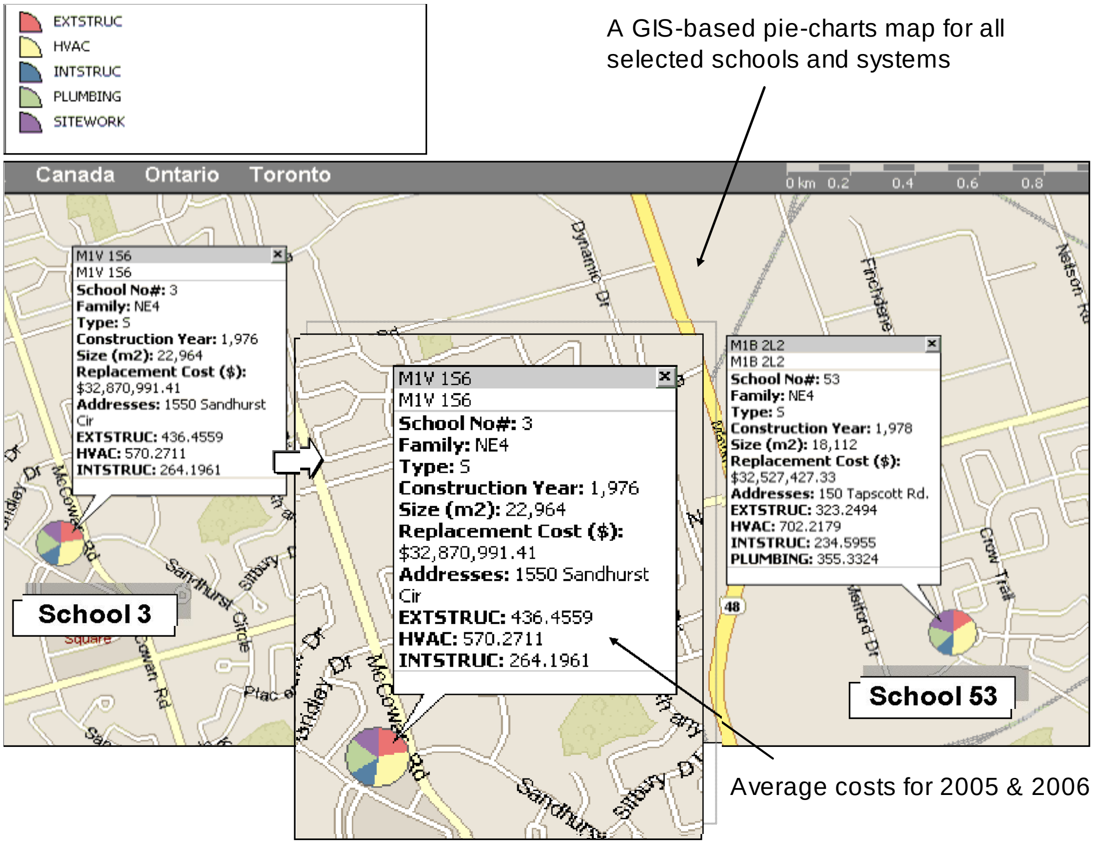


Figure 5.10b: A Chart Report Generated at the Family-Trades Level



M1V 1S6
M1V 1S6
School No#: 3
Family: NE4
Type: S
Construction Year: 1,976
Size (m2): 22,964
Replacement Cost ($): $32,870,991.41
Addresses: 1550 Sandhurst Cir
EXTSTRUC: 436.4559
HVAC: 570.2711
INTSTRUC: 264.1961

M1V 1S6
M1V 1S6
School No#: 3
Family: NE4
Type: S
Construction Year: 1,976
Size (m2): 22,964
Replacement Cost ($): $32,870,991.41
Addresses: 1550 Sandhurst Cir
EXTSTRUC: 436.4559
HVAC: 570.2711
INTSTRUC: 264.1961

M1B 2L2
M1B 2L2
School No#: 53
Family: NE4
Type: S
Construction Year: 1,978
Size (m2): 18,112
Replacement Cost ($): $32,527,427.33
Addresses: 150 Tapscott Rd.
EXTSTRUC: 323.2494
HVAC: 702.2179
INTSTRUC: 234.5955
PLUMBING: 355.3324

A GIS-based pie-charts map for all selected schools and systems

Average costs for 2005 & 2006

Figure 5.10c: A GIS-Based Report Generated at the Family-Trades Level

The reports generated have the potential to help users extract useful information. For example, the average expenditures on plumbing dropped for all NE4 schools (Schools 3 and 53). In school 3, the average costs have decreased from $506 in 2005 to $242 in 2006, while those for school 53 have decreased from $487 to $196 in the same period. A family trades personnel can use this extracted information to draw conclusions such as the following:

- The systems of the two schools, in general, show improvement.
- The systems are likely in an acceptable and functional condition.
- Systems in some schools may need special attention, such as the HVAC system in school 53.

The GIS-based report in Figure 5.10c is also a useful visual tool that allows a comparison of two schools which are almost the same age (school 3 was constructed in 1976, and school 53 was constructed in 1978). The pie charts for both schools look similar, as both are secondary schools whose sizes are almost the same: 22,964m^2 and 18,112m^2. Thus, the visual presentation of the data enables decision makers to quickly detect similarities and differences that can be considered in relation to demographic characteristics.

5.5 Using the Model to Infer Hidden Information

One of the major benefits of the model is its ability to identify new/hidden information in the large amount of available data. This hidden information can provide decision makers with more versatile views of the data. For example, it is possible to use the available maintenance data to support the prediction of the condition of a component. The total maintenance costs and total number of work orders can be defined and used to differentiate among good, fair, poor, and critical conditions of a system. This analysis is not shown in the original row data and is very beneficial for making decisions about asset management, such as capital renewal.

As an example, this data analysis is applied to the HVAC systems in the elementary schools of NE1 area in 2006. The user interface previously described was used to generate a pivot chart at the family-trades level for the related data (Figure 5.11). The chart was then modified by defining the four zones related to the four condition categories. It is noted that Figure 5.11 shows the total costs of HVAC maintenance work orders for NE1 schools in 2006 that are normalized according to school size and sorted in ascending order. Dividing the chart into approximately four equal zones produces the range of costs that define the condition categories according to the total work orders cost per 1000m^2 of school area, as follows:

- Good Condition: \$0 - \$1,999
- Fair Condition: \$2,000 - \$3,999
- Poor Condition: \$ 4,000 - \$5,999
- Critical Condition: \$6,000 or more

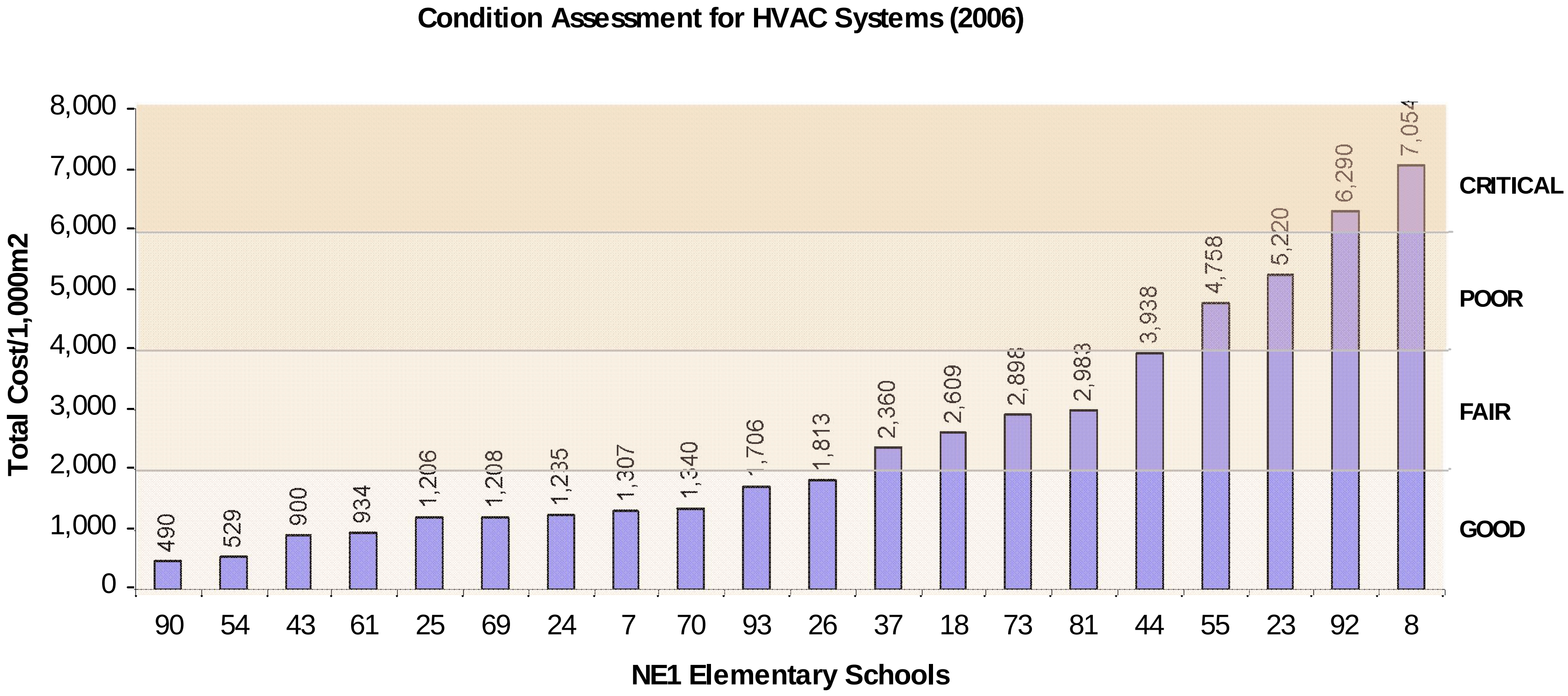


Figure 5.11: Categorizing the Condition of HVAC Systems Based on Total Costs in 2006

Similarly, another chart was generated to categorize conditions based on the total number of maintenance work orders (normmalized according to school size, Figure 5.12). Again, dividing the chart into approximately four equal zones provides the ranges of work orders that define the condition categories, according to the total number of maintenance work orders per 10,000 m^2 of school area, as follows:

- Good Condition: 0 - 49
- Fair Condition: 50 - 99
- Poor Condition: 100 - 149
- Critical Condition: 150 or more

This analysis provides a simple approach to predicting the condition of a specific system for selected schools. A summary of the predictions is shown in Table 5.2.

Table 5.2: Using the Model to Identify Hidden Information

Family	Type	System	School no.	Condition 2006	Condition 2006
				Based on Total Costs	Based on Work Orders
NE1	ELEMENTARY SCHOOL	HVAC SYSTEMS	7	GOOD	FAIR
			8	**CRITICAL**	**CRITICAL**
			18*	**FAIR**	**POOR**
			23	POOR	FAIR
			24	GOOD	GOOD
			25	GOOD	FAIR
			26	GOOD	FAIR
			37*	**FAIR**	**POOR**
			43	GOOD	GOOD
			44	FAIR	FAIR
			54	GOOD	FAIR
			55*	**POOR**	**CRITICAL**
			61	GOOD	GOOD
			69	GOOD	FAIR
			70	GOOD	FAIR
			73	FAIR	FAIR
			81	FAIR	FAIR
			90	GOOD	GOOD
			92	CRITICAL	FAIR
			93	GOOD	FAIR

*Schools that need to be double-checked

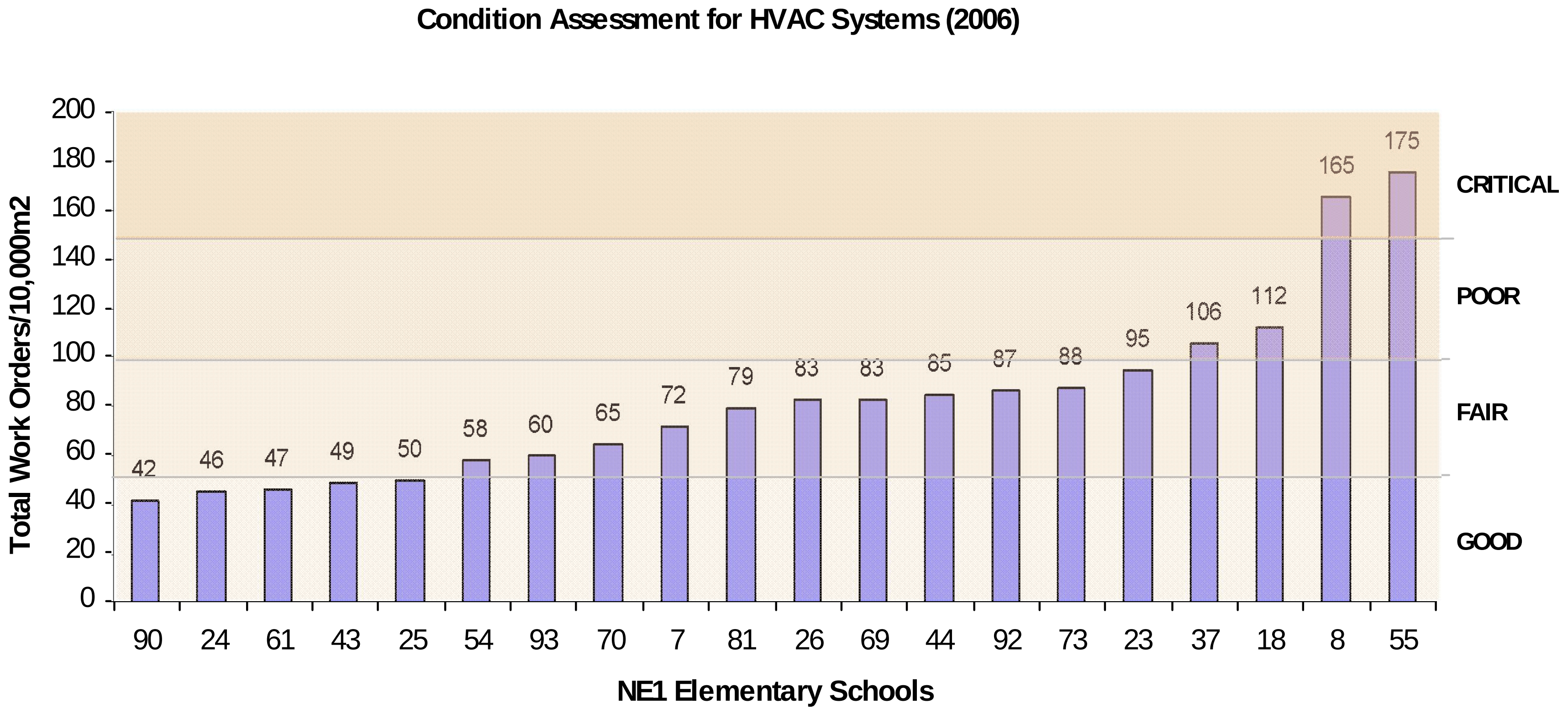


Figure 5.12: Categorizing the Condition of HVAC Systems Based on Total Number of Work Orders in 2006

From Table 5.2, comparing the condition predicted based on the total costs versus those predicted using the number of work orders indicates a measure of the reasonableness of the prediction. A decision maker can draw useful conclusions that can help with future planning, such as the following:

- In general, the condition of the HVAC systems assessed based on total costs and work orders show some consistency.
- Some schools, such as 18, 37, and 55, need to be double-checked by the inspectors.
- Schools 18 and 37 show a large drop in condition as measured by the two types of predictions (total costs and total number of work orders). The reason for this discrepancy would need to be determined.
- schools 55 shows an inclination towards being in critical conditions and should be monitored.

5.6 Conclusion

In this chapter, a real-life case study using the data for two years of maintenance and repair jobs for a large number of schools has been implemented on the proposed Multi-Level GIS-Based Data Management Model. Its primarily advantage is that it allows decision makers at different levels of management to visualize data in text, chart, and GIS-based reports. Moreover, these different types of reports generated can help extract useful information that is hidden in the main database, such as an assessment of the current condition of a system in school buildings. Using both the total maintenance costs and total number work orders as indicators for condition provide versatile analysis of the data.

Chapter 6

Conclusions

6.1 Conclusions

The main objectives of the present research are to give an overview of the unique nature of the data related to infrastructure assets, particularly school buildings; to highlight the need for an efficient and inexpensive means of extracting meaningful information from these data; and to develop a GIS -based Data Management Model for managing, reporting, and visualizing maintenance and repair data for school buildings. To ensure the usefulness of the proposed model, real-life data for two years of maintenance and repair jobs for 93 schools were collected from the Toronto District School Board (TDSB) and were used to develop the model. The model's integration of spreadsheets (MS Excel) and GIS software (MS MapPoint) enable it to produce reports that summarize the data in new, customized formats that provide meaningful support for decision making at a variety of management levels.

The proposed model was designed as a GIS-based Data Management Model for building maintenance-data with Visual Basic for Application (VBA) code for integration at its core. The model has been demonstrated to have the following capabilities:

- It shows flexibility to handle the huge sets of maintenance and repair data.
- It extracts meaningful information from data formatted as text and tables through friendly interfaces.
- It considers different levels of management by providing features and reports that satisfy varied interests and preferences.
- It presents the selected characteristics in formats that are easy for the human cognition system to understand.
- It allows users to select, filter, automate, and visualize information through friendly interfaces and varied reporting formats.
- It utilizes the VBA programming language to combine the benefits of spreadsheets with the flexible features of GIS software.
- It has the ability to accommodate additional data beyond the amount in the case study.
- It allows different levels of management to evaluate the performance of the assets for which they are responsible.
- From the large amount of data available, it can identify new/hidden information, such as the current condition of a system.

To demonstrate the usefulness of the model and illustrate its capabilities, a real-life case study of maintenance and repair data was used. The variety of reports generated proved the suitability of the model for managing, reporting, and visualizing maintenance and repair data. The model was presented to the TDSB, where it appealed to the decision makers and is being considered for possible adoption and integration with their maintenance and repair system.

6.2 Future Research

The proposed model has been proven to be effective in facilitating the decision-making process for huge sets of infrastructure maintenance data in a manner that considers different management levels. However, a number of improvements could be investigated in future research:

- The model could be further experimented with larger number of schools.
- The integration between a well-designed relational database system such as MS Access and more sophisticated GIS software such as ArcGIS or ArcView could be investigated.
- A new GIS-based model could be built that allows users to add, edit, and store new maps in order to provide a more versatile presentation of the information.
- The model could be linked to the existing functionality of the maintenance and repair group at the TDSB.
- The integration of the model with a complete asset management system could be investigated in order to provide speedy condition predictions.

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