# Developing a facility management system for vertical infrastructure of Iowa

by

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Signatures have been redacted for privacy

**To Dr. Rowings and my family.**

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# CHAPTER 1. INTRODUCTION

## Background

The State of Iowa owns and manages a large number of public buildings (vertical infrastructure). According to "Iowa Infrastructure 95" (Rowings and Harmelink, 1994), approximately $3.2 billion is needed for vertical infrastructure maintenance. As of February 12, 2000, the vertical infrastructure consisted of 875 buildings, with 10,270,598 square feet. This inventory encompasses everything from a one-room shed to highly sophisticated buildings comprising thousands of square feet. These buildings range in age from several decades to newly constructed, and from unique, individual buildings to members of a group of similar buildings. This state-owned property is grouped into 7 designated areas: Capitol Complex, Culture Affairs, Public Safety, Corrections, Human Services, Commerce, and Veteran Affairs.

Effectively managing maintenance and repair (M&R) of such a widely diversified building inventory is a challenging task. Effective maintenance requires knowledge of the building inventory (sizes, types, and interrelationships of component parts), physical condition (measures of deterioration of individual components and the building as a whole), component performance (condition over time), and the impact of component performance on overall building performance. The term "maintenance" is broadly applied here. It includes preventive and routine maintenance, minor and major repairs, rehabilitation, and replacement if a component has deteriorated to the point where partial or full replacement is most cost effective.

In 1994, Iowa State University researchers developed the "Report of Infrastructure Needs in the State of Iowa." (Rowings and Harmelink, 1994) To assess Iowa vertical infrastructure maintenance data, a written survey was sent to virtually all infrastructure controlling agencies. Reports were presented for different types of infrastructure, which include public schools, cities, the Department of Management, hospitals, waste water systems and highway, roads systems. The focus of the surveys was to identify which facilities and components require the most maintenance and identify the facility's values at that time. The study showed the need for automated management systems due to the large quantity of information to be managed. Since most of the data collection, entry, and retrieval have been manual, there were no detailed facility or components reports at the maintenance level nor an easily accessible condition or budget prediction database.

## Problem Statement

The Department of General Services (DGS) of Iowa has not had a comprehensive strategy for maintaining its facilities. Rather, each agency had its own way to rate property conditions, prioritize repairs, and allocate resources. As a result, the DGS could not be certain that the most critical properties in need of maintenance and repair were targeted. The DGS, consequently, could not be assured that its funding for maintenance and repairs provided the best return on its investment.

Specifically, there are three fundamental facility management problems.

1. Assets Inventory Problem—Since there are no precise inventory records, no facility manager is able to answer the following four questions accurately.

- What buildings are present?
- What systems are installed in those buildings?
- What components are contained in those systems?
- What are the types, sizes, and materials of those components?

2. Maintenance problem—One of the most pressing problems facing the Iowa Department of General Services is the condition of its vertical infrastructure. Making good maintenance decisions requires years of practical experience and judgment. Guidance on whether to perform maintenance, what type of maintenance to perform, and how much the maintenance will cost is greatly needed.

However, the DGS has not had complete and sufficient information input resulting in reliance on building managers to identify and report work needs to the DGS. Maintenance of existing infrastructure, public buildings and other public facilities, often does not receive adequate attention. This is especially frequent in times of tight budgets when the likely cost and service consequences of not doing maintenance are seldom reported. Management has thus become reactive instead of proactive—work is primarily dictated by component failures and the demands of "customers". Objective planning is sacrificed. Although the DGS prepares annual work plans, few are followed or used because resources are lacking and facility managers do not have the information to support them.

When maintenance management is accomplished reactively, maintenance becomes expensive. For example, as pavement condition deteriorates, the funds needed for M&R increase several times (Figure 1.1). A similar relationship would be expected to hold for building components. Since a condition index-rating system does not exist for most building

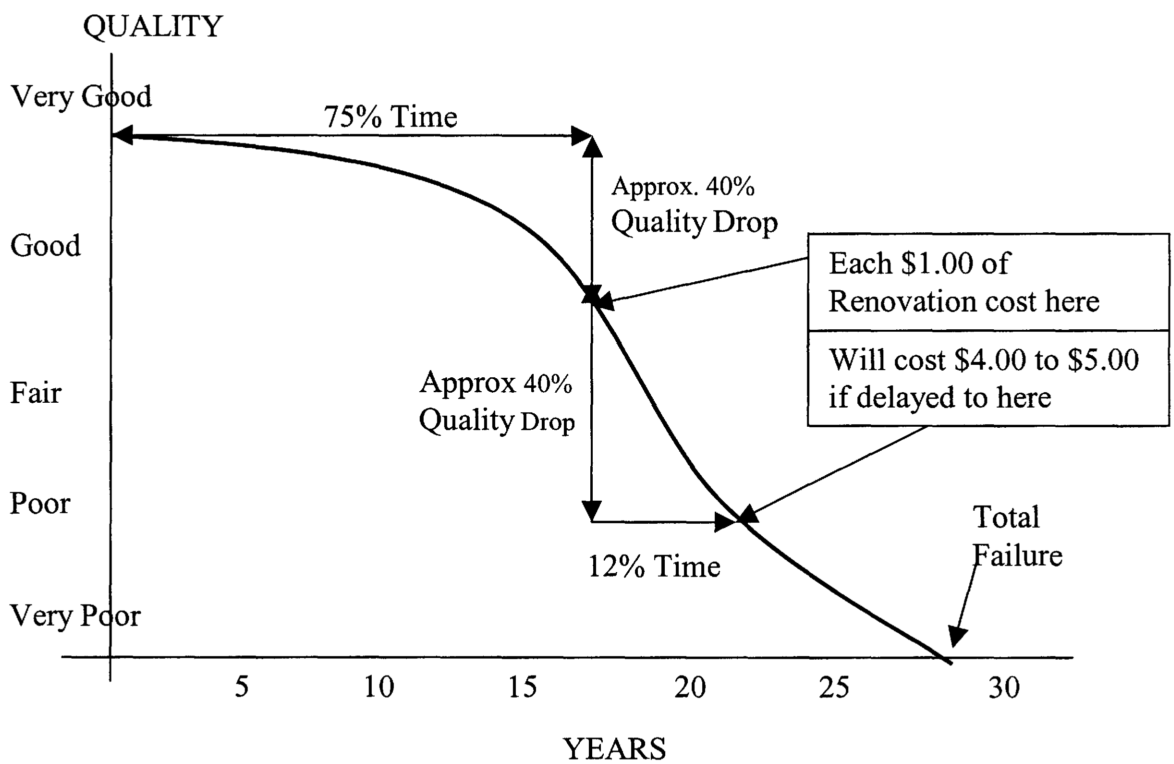



Figure 1.1 Pavement Deterioration vs. Time
*Pavement new at Time = 0 years* (Uzarski, 1990)

components, this relationship cannot be demonstrated. Nevertheless, when work tends to be accomplished reactively, the facility or component condition is generally found at the lower end of condition index scale. Major restoration of components is very costly; hence other needed work must be deferred due to budget constraints. Although immediate M&R needs may be met by this approach, the process is self-defeating because goals are not attained in a resource-constrained environment.

3. Condition Assessments Problem— The DGS has not had a structured objective condition assessment system for buildings and most building components. Without such assessment, and a means for analyzing and reporting key building

information, it is impossible to simultaneously assess current conditions, accurately project future conditions, and track building performance. Key components cannot be properly evaluated, nor can deficiencies be identified. When determining maintenance needs, interaction between components is difficult to evaluate, and work may not be effectively planned, budgeted, or accomplished. Also, if the facility is made up of a large number of buildings, it is difficult to budget funds effectively and allocate them where they are needed most. In addition, it is difficult to properly institute preventive maintenance programs, evaluate their effectiveness, and prioritize work. Optimal M&R programs cannot be attained.

In the absence of an overall, comprehensive management strategy for maintaining the service's infrastructure, each agency has established its criteria for assessing the condition of its properties and the urgency of repairs, prioritizing maintenance needs, and deciding how much to allocate for maintenance and repair. As a result, the facility management system has the following weaknesses:

- Little or no linkage between condition assessment and the DGS budget estimation.
- Cost estimates generally not accurate.
- Ratings too subjective.
- Ratings too broad and oversimplification of conditions
- Ratings not timely or informative.

A good condition assessment system should be created that would allow DGS to accurately answer the following questions:

- What is the condition of the buildings measured?
- In what condition are the buildings and their components?
- What condition is acceptable and desirable?

Due to these problems discussed above, the DGS of the State of Iowa decided to fund a research project to improve Iowa infrastructure management.

## Literature Review

### Infrastructure vs. Vertical Infrastructure

In recent years the term " infrastructure" has emerged from technical obscurity to appear frequently in the press. Many people now recognize this word as a shorthand reference to a diverse system of facilities and services, ranging from airports to energy supply. Unlike public works, the term "infrastructure" incorporates both physical assets and their economic, social, and political roles, and refers to public enterprises, as well as to a rich mix of private and joint public-private enterprises. Constructed facilities—infrastructures, as some experts term them—are at the core of the concept, but are only part of the system. (National Research Council, 1994)

According to National Research Council (1987), the term "infrastructure" includes:

> …both specific functional modes—highways, streets, roads, and bridges; mass transit; airports and airways; water supply and water resources; wastewater management; solid waste treatment and disposal; electric power generation and transmission; telecommunications; and hazardous waste management—and the combined system these modal elements comprise. A comprehension of

> infrastructure spans not only these public works facilities, but also the operating procedures, management practices, and development policies that interact together with social demand the physical world to facilitate the transport of people and goods, provision of water for drinking and a variety of other uses, safe disposal of society's waste products, provision of energy where it is needed, and transmission of information within and between communities. (National Research Council, 1994, pp 12)

The type and function of the facilities in each class varies tremendously. Both the relevant criteria and the analysis process to identify needs for a bridge facility are very different than those for a state capitol. The planning and management capabilities of the agencies and entities responsible for the capital needs of each infrastructure class vary also (Rowings, 1994). For these reasons, it is necessary to use different methods to determine needs for each of the different infrastructure types.

Vertical infrastructure is the type of infrastructure studied in this thesis. Systems of buildings, such as schools, health care facilities, government offices, prisons, etc., should be added to the specific types of what the National Research Council described above. These facilities—not individual buildings tied together by the functional and administrative systems they house—provide important services to the public at large in much the same fashion as highways and water supply facilities. Therefore, they are assigned a specific category, "vertical infrastructure," compared with horizontal infrastructures that include transportation systems, wastewater systems and other such systems.

**The Benefits of Infrastructure Research**

Despite the broad scope and diversity of infrastructures, several common characteristics comprise an intellectual basis for addressing infrastructures as a system and define the benefits research may yield.

1. Infrastructure is, to use the economist's term, "capital intensive," meaning it involves materials and equipment rather than labor input. Capital is required in large concentrations that cannot be finely subdivided. Research can increase reliable productivity of these capital investments/public assets that serve broad needs in the economy.
2. Infrastructures, especially those that are long standing and difficult to remove or retire, are routinely designed to meet demands projected for three decades or more into the future. Maintenance and periodic renovation are required, but the underlying structure changes little over a long period of time. When some old facilities are abandoned because they are no longer thought useful, the facilities themselves are often left in place, too costly to remove. The long-term design lifetime of infrastructure facilities needs to be reconsidered. Technology for cost-effective downsizing, adaptive reuse, or retirement and demolition of facilities may be needed. (National Research Council, 1993) Research can enhance infrastructure flexibility to respond to change—growth, decline, and composition—in such a way that the infrastructure can still perform its function well.
3. The facilities and users of physical infrastructure are linked in extensive geographically complex networks; e.g., the state patrol system, the state penitentiary

system and the state administrative office networks. These networks stretch over large areas, and often quickly transmit changes from one part of the system to another. Failure of small elements can have drastic consequences on large parts of the system. Research can improve the ability to understand and manage network performance.

4. Infrastructures are as support for other social and economic activities, an encouragement to economic development, or as a short-term source of jobs. A large amount of infrastructure is created because it serves demands derived from other activities, such as demands for reliable transportation safety, demands for good law executives, or for protection of historic sites.

Service demands typically influence the facilities and management practices of infrastructure in order to determine the performance that infrastructure delivers. Principles of economics, political science, sociology, psychology, and other behavioral sciences are primary sources of knowledge about these demands and how they impinge on infrastructure. Research can enhance understanding and ability to measure and manage demand for infrastructure services.

5. Because infrastructure facilities are typically large, geographically extensive, and used by many people, infrastructure development and operations often have substantial environmental and social impacts. In the past, these impacts have frequently been poorly estimated or neglected in planning and design, and often are poorly managed within the context of traditional governmental, economic, and institutional relationships. The role of infrastructure as a factor shaping urban development is only partially described by current theory and statistical studies, as

are the economic and social cost of inserting new systems into already developed areas. (H. Lee; R. Deighton, 1995) Research can enhance our ability to avoid or mitigate adverse impacts of infrastructure maintenance.

## Prior Studies Focusing on Infrastructure Maintenance

Infrastructure research started in the 1980's. A variety of research institutes were involved in infrastructure-related missions. For example, the federal government developed several research and development (R&D) centers in the 1980s. Currently, the major participants are academic institutions, government and private research laboratories, and private companies. Research and development activities applied to infrastructure are performed largely under the auspices of civil engineering programs or units associated with the development and management of public works. Programs in electrical, mechanical, water resources, construction engineering, architecture, and urban planning also included topic-related infrastructure systems and technology. However, most past works were developed to deal with one type of infrastructure alone, such as transportation or water supply. (National Research Council, 1994) Few of the past efforts were comprehensive or aimed at infrastructure as a multi-functional system of facilities and services.

Later, a few organizations established research centers under the title of "infrastructure." National Research Council published the first complete infrastructure research in 1984. It primarily addressed management and economic needs, such as the role of standards and risk analysis in infrastructure decision making, life-cycle cost analysis strategies for infrastructure maintenance and repair, methods for evaluating benefits and costs of various levels of system performance, and effective diffusion of innovation into practice.

Other National Research Council research (1985) included a workshop that attempted to identify technological alternatives—new systems, materials, and devices—for replacement of the present urban infrastructure systems. A call for further research on the integration of various infrastructure elements emerged from the workshop.

An extensive discussion of infrastructure research is contained in an Office of Technology Assessment (OTA) report concerning the federal role in infrastructure policy (1990). This report includes a chapter on comprehensive technologies for infrastructure, identifying four technologies on which research would be appropriate:

- measurement, instrumentation, and nondestructive evaluation;
- information and decision systems, including maintenance management information systems, geographic information systems, artificial intelligence, and simulation models;
- communications and positioning systems, including signal systems and the use of satellites;
- field construction technologies, including trenchless construction technologies, tunnels, soil improvements and stabilization. (National Research Council, 1993)

This report is the first to suggest establishing an information and decision system, but it is only a general concept.

At the 1991 Civil Engineering Research Needs Forum held in Washington, D.C. by Civil Engineering Research Foundation (CERF), a more detailed plan of infrastructure research was presented. Participants in this forum identified and ranked ten high-priority research topics:

- developing tools to make intelligent management decisions
- finding new ways to finance infrastructure investments
- extending the useful life of infrastructure
- protecting bridges from natural hazards
- identifying structural problems by diagnosis
- removing institutional barriers to innovation
- ensuring economic benefits from public works investments
- improving water-resource systems data through new technology
- mitigating coastal damage from natural hazards
- protecting dams against earthquakes and floods (National Research Council, 1993)

Because the majority of infrastructure research is on the theory level, no effective tools have been developed. The above statements of infrastructure research needs bear great similarities, particularly in their emphasis on materials, condition assessment, and monitoring. These research topics provide an excellent framework for later studies.

In late 1993, research of infrastructure maintenance management entered into a new phase. First, two major approaches were developed to deal with the too prevalent practice of deferring infrastructure maintenance. One approach requires the preparation of maintenance management systems as part of planning and federal funding of state and local surface transportation projects under the *Intermodal Surface Transportation Efficiency Act Of 1991* (ISTEA). The other approach is an initiative by the Governmental Accounting Standards

Board (GASB) to develop guidelines for reporting information on capital assets. (U.S. Advisory Commission on Intergovernmental Relations, 1993)

GASB's work is expected to include guidelines on reporting the condition of these assets, their ability to meet service needs, and the estimated cost (if any) to return assets to acceptable condition. GASB sets accounting standards to guide state and local governments and works with the Federal Accounting Standards Advisory Board (FASAB), a body that recommends federal accounting standards and is beginning to consider capital expenditure accounting issues.

Under ISTEA, new construction of highways and transit facilities is no longer the central focus; good management and maintenance of existing facilities now receive emphasis. Three maintenance management systems are required before federal grants can be issued. They cover pavements, bridges, and public transportation facilities and equipment. The purpose of these management systems is to develop proposals for optimal allocation of limited funds to help minimize life cycle governmental and user costs. Analysis of maintenance needs and usage of inventory and condition assessment data are required.

Two other examples of maintenance planning actions are listed below:

- New York City has established a regular condition survey of all city-owned buildings and public facilities as a result of a city charter requirement enacted after the West Side Highway collapse ten years ago. The survey is automated and provides well-justified cost estimates of maintenance needs for the city's annual budget process.
- The U.S. Department of Energy has established a Capital Asset Management Program (CAMP) based on condition assessments, life cycle planning that

evaluates alternative "what if" scenarios, and prioritization of maintenance needs in the context of changing departmental missions.

The U.S. Army has made significant contributions to infrastructure research because it not only has a relatively mature maintenance planning process, but it also works on facility management constantly. In 1991, the U.S.Army Construction Engineering Laboratory (USACERL) published a two-volume technical report addressing the complete scope of the facility layaway process for U.S.Army installations, such as deactivation, periodic maintenance and repair, and reactivation (Uzarski et al, 1990). The highlight of this report, *Layaway Procedure for U.S.Army Facilities, Volume I and II*, was a set of detailed M&R inspection checklists for use by personnel responsible for layaway facilities. This checklist was developed based on the professional opinions of CERL researchers. The intent in this report was to make the component checklists as generic as possible in order to promote the widest possible range of use. This checklist is an excellent guide for future research on building component checking and analyzing.

In addition, the USACERL is in the process of creating Engineered Management Systems (EMSs) to aid the Directorate of Engineering and Housing and Facility Engineers in performing effective maintenance management (Uzarski, 1989b). These include a few software packages like PAVER, RAILER, PIPER, ROOFER, PAINTER, SCALER, and BRIDGER. Most of these systems apply to single-component facilities (PAVER and PIPER) or a major component within a facility (ROOFER, SCALER and PAINTER). RAILER and BRIDGER apply only to several components. (Uzarski et al, 1990) The goal of an EMS is to use engineering technology to systematically determine when, where and how best to maintain facilities. No EMS currently exists for Army buildings yet, although ROOFER or

PAINTER focuses on specific building components; additionally EMS cannot solve budget estimation.

The U.S. Army Corps of Engineers' Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program is making a lot progress in the infrastructure research field also. REMR was conducted in two phases, beginning in 1984. Phase 1 of the program was a 6-year, $35 million effort that was completed in 1989. This phase clearly demonstrated the benefits of research to obtain more value for the dollars spent on infrastructure research activities. The estimated dollar savings from the use of the research results exceeded $68 million over a 5-year period following completion of the Phase 1 effort. Phase 2 of the program was initiated in 1991 at a cost of $31.2 million and was completed in 1998. The dollar savings from the use of the Phase 2 research are estimated at $200 million. (Aguirre, 1998; McCleese, 2000) For management purposes, the program was broken down into seven broad problem areas:

- Concrete and Steel structures
- Geotechnical
- Hydraulics
- Coastal
- Electrical and Mechanical
- Environmental Impacts
- Operations Management

Compared with previous research, the major advantage of these REMR Management Systems is their ability to provide maintenance managers at all levels with tools to promote easier and more effective maintenance and budget planning. Moreover, the REMR Programs created procedures and assessment methods that allow the condition of structure to be expressed numerically in order to take advantage of the benefits available from the use of microcomputers in maintenance management.

**Suggested Research Areas of Vertical Infrastructure**

In view of the United State's infrastructure problems and the role of the National Science Foundation's (NSF) role as a research sponsor, the Committee for Infrastructure Technology Research (CITR) developed a research agenda in seven broad areas. (National Research Council, 1994)

1. Total System Inventory
    - Analytical inventories of infrastructure systems
    - Statistical analysis of infrastructure
    - Quick response infrastructure management
2. Analysis and Decision Tools
    - System models
    - Anticipating consequences of catastrophic events
    - Faster integration of new technology into design practice
3. Condition Assessment and Monitoring Technology
    - System wide condition assessment
    - Structural assessment
    - Site characterization
4. Information Management

- Advanced data acquisition and management methods
- Network analysis methods
- Education for infrastructure management

5. Science of Materials Performance and Deterioration
   - High performance of materials
   - Characterization of damage, deterioration, and aging
6. Construction Equipment and Procedures
   - High performance construction techniques
   - Construction waste disposal
   - Underground construction
   - Construction safety
7. Technology Management
   - Achieving high performance
   - Technology adaptation to infrastructure
   - Institutional obstacles to innovation

In the terms of CITR, "these areas are essentially clusters of common science and technology issues that researchers can study both as areas for general expansion of scientific knowledge (e.g. in mathematics, economics, computer science) and as problems to be solved for individual infrastructure modes." (NRC, 1994) Specifically, the Iowa 1999 Vertical Infrastructure Project focuses on the first four areas. Therefore, this thesis also puts emphasis on these four areas, which are inventory, condition assessment, decision tool development, and information management.

## Approach and Objectives

### The Project of Iowa Vertical Infrastructure Inventory and Assessment

In 1999, along with facility audits performed by local designers and contractors, Iowa State University (ISU) researchers finished a project called " Iowa Vertical Infrastructure Inventory and Assessment." This project was intended to develop an inventory and assessment system for all the Department of General Services (DGS) facilities and to execute the initial evaluation for the purpose of identifying the most critical projects requiring attention.

The system includes an inventory and assessment process, and a microcomputer database capable of being queried for needed infrastructure and asset management information in order to support the operational needs of the range of DGS clients. The database was developed with the intent of functioning with minimum staff for maintenance of the database and periodic reassessments of inventory to keep the database current with regard to facility condition and utilization. The database is able to support any decision-making and funding request made by the DGS. The process of " Iowa Vertical Infrastructure Inventory and Assessment" involves three basic modules as demonstrated in Figure 1.2:

- Formulation of the requirements
- Evaluation of existing facilities
- Comprehensive development of budgets

The details of this system and the database will be discussed in the following chapters.

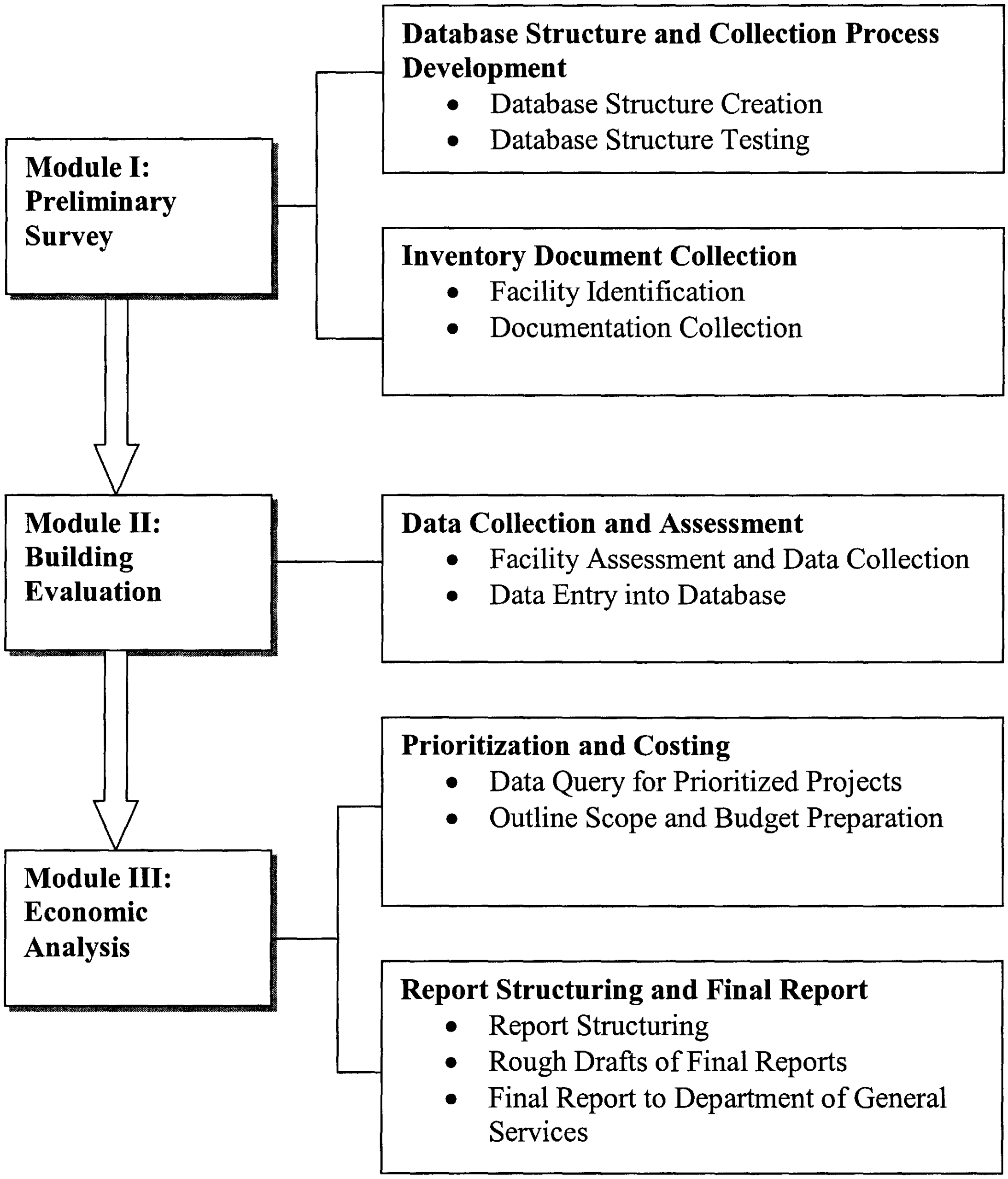



Figure 1.2. Three Modules of Project of "Vertical Infrastructure Inventory and Assessment of State of Iowa"

**VIIAD Objectives**

A specific tool, "Vertical Infrastructure Inventory Assessment Database" (VIIAD), was developed using database management system technology. VIIAD combines building engineering technology, facility management principles, models and analysis procedures, and is designed to assist in management and funding decisions and enable leadership to implement non-incremental, comprehensive decisions on Iowa vertical infrastructure issues. To be meaningful, the VIIAD should incorporate a minimum level of inspection, contain building information from available databases and condition ratings, and use microcomputer software technology. It must also be flexible enough to be expanded easily. In general, the objectives of VIIAD are as follows:

1. Compilation of a systematic and consistent inventory of the vertical infrastructure of the State of Iowa.
2. Development of condition assessment system for the vertical infrastructure considering various infrastructure categories, construction of new facilities, and maintenance and renovation of current facilities.
3. Identification of recent and current expenditures for infrastructure construction, maintenance, and renovation.
4. Development of specific assessment priority lists for vertical infrastructure.
5. Creation of an efficient method to provide information for budgeting decisions.

## Description of the Plan of Work

This thesis consists of five chapters. The first chapter gives an overview of infrastructure and its management. It began with the infrastructure management problem statement followed by a literature review, which provided some basic knowledge about infrastructure, vertical infrastructure, the benefits of infrastructure research and the suggested research areas. Then the objective of VIIAD, the specific tool for infrastructure management—Vertical Infrastructure Inventory and Assessment Database (VIIAD) was presented.

Chapter 2 covers the theory of vertical infrastructure management system (VIMS) development. This chapter analyzes the information needs in facilities maintenance procedure and introduces two major technologies for computer-aided facility management, which are condition assessment and budget estimation technologies.

Chapter 3 focuses on mechanism and organization of the VIMS. This chapter presents how the building system is divided according to its architectural, mechanical and electrical functions and how the building inspection procedure be performed. In addition, the key technology about building and components condition assessment is discussed in detail.

Chapter 4 presents the features of VIIAD. For example, VIIAD can recognize and execute any kind of query related to vertical infrastructure. Additionally, this chapter presents VIIAD's potential applications, which include suggesting maintenance and repair plans or calculating an alternative cost model.

The last chapter, Conclusions and Recommendations, goes over previous analyses and provides a summary of the findings of the study. The advantage of this study and the future research areas are also discussed.

# CHAPTER 2. THE VERTICAL INFRASTRUCTURE MANAGEMENT SYSTEM AND TECHNOLOGY

In order to support the infrastructure management needs discussed in chapter 1, an infrastructure management system and a software application were designed. This chapter gives an overview of what are the infrastructure management system and applied technologies. In addition, building oriented software programs, condition assessment methods, budget prediction methods are discussed in this chapter.

## Technologies of Vertical Infrastructure Maintenance System

### Perspective on the Building Orientated Software Programs

A literature review was performed to determine what building maintenance management programs, systems, or technologies are currently available or are under development. According to this review, the main categories of available software are equipment programs and facility programs. The equipment programs focus on planning regular equipment preventive maintenance schedules, parts inventory, producing work and purchase orders, and storing records on maintenance personnel. The facilities programs are used to manage energy efficiency, hold records on facilities inventory, such as rooms and parking spaces, and provide analysis and planning of space for effective building operation. None of the program's survey addressed using inspection checklists, condition indexes or developing prioritized work plans based on inspection results. Therefore, there is a need to develop a building oriented program to integrate the collection of physical data and incorporate that data into decisions on maintenance practice.

The ultimate goal of component inspection is to generate information to make optimal decisions about M&R. From this broader perspective, inspection technologies involve not only capturing data from in-situ components or facilities, but they also address the systems that can transform this physical data into useful information to support management decisions. Such systems use database management and information processing concepts.

A wide range of database management technologies is available today. Information processing capabilities have expanded to include simulation, optimization, and knowledge-based analysis and interpretation. Software for implementing these database and information processing capabilities is available for any size computer hardware. The relationship between technology and information requirements is discussed in the next section.

**Information Requirements and Technological Potentials**

A general mode of how information requirements are structured for a DGS facility will help illustrate which technologies would be appropriate at different levels in the maintenance management process. Three distinct levels of information are required to support this process (Figure 2.1). Level I, the DGS level, deals with maintenance budget decisions, priorities, project justification, and manpower programming, and needs to be supported by useable information generated from an accurate assessment of each vertical infrastructure. Level II, the building level, must be able to provide information up the line to support management needs in Level I. It must also be able to generate and store information for the component level, supporting the detailed inspections and results done in Level III.,

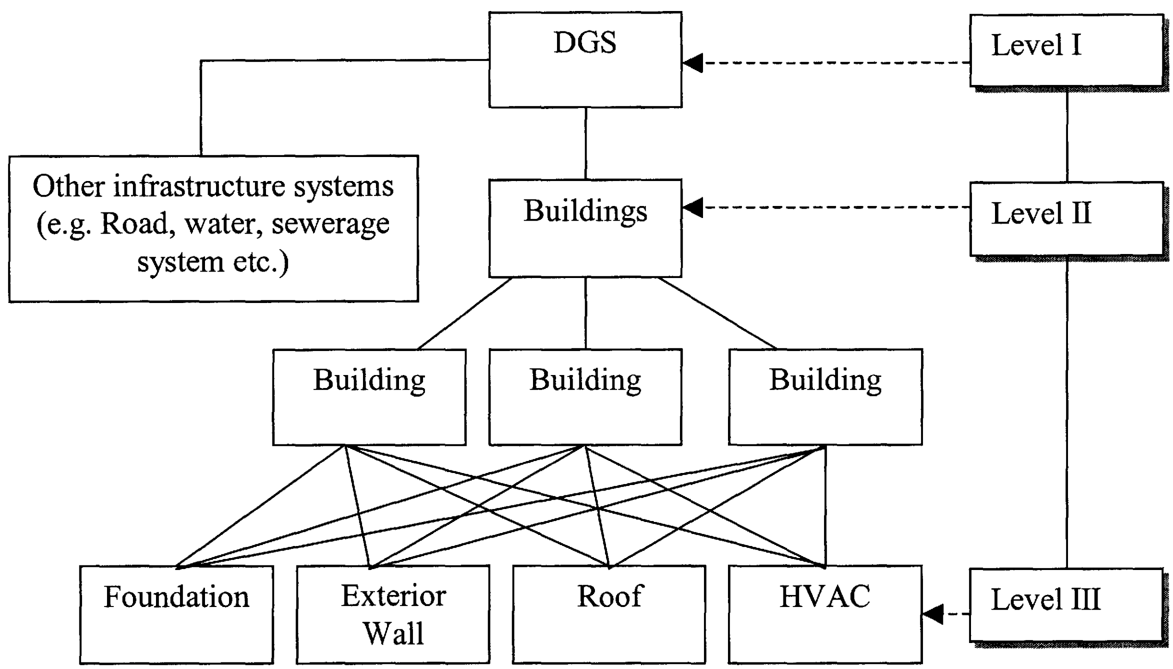



Figure 2.1 Information Levels

the component level, must provide the precise condition data for individual components within a building.

Table 2.1 relates management decision and information requirements of those three levels to technology options. It is structured to show how management decisions, the information required to support these decisions, and the appropriate technologies to capture the needed information vary, depending on the decision level. The approach to capturing, handling, and using the necessary information also varies with the decision level. “Decision types” indicates the kinds of decisions made at each of the three levels. “Information requirements” indicates the type of information and data needed to support these decisions. “Approach” suggests generic approaches to providing the needed information and data, and “technology” indicates specific technologies that could support the implementation of these

Table 2.1 Information Technologies For Maintenance Decisions

| Decision Level | DGS | Building | Component |
|---|---|---|---|
| Decision Type | Inspection Programming And Resource Allocation | Inspection Methodology | Frequency, Extent, And Technology of Inspection |
| | Maintenance Decisions | Maintenance Specifications | Repair/Replace/ No Action |
| | Maintenance Budget | Repair/Replace/No Action | |
| Information Requirements | Inventory Data | Inventory and Inspection of Facilities to Determine Condition | Physical Characteristics |
| | Condition Assessment | Condition Assessment | Condition Assessment |
| | Cost of Maintenance | Cost of Maintenance | Cost of Maintenance |
| Approach | Automation to Aid In Data Acquisition | Data Access and Database Management | Inspection, Condition Rating and Data Interpretation |
| | Database Management | Decision Models And Life-Cycle Analysis | Life-Cycle Cost Analysis |
| | Resource Allocation | | |
| | Optimize Life-Cycle Cost | | |
| Technology | Inventory Management | DBMS | Nondestructive Evaluation Methods |
| | Database Management Systems (DBMS) | Expert Systems | Expert Systems |

(Uzarski, 1989b)

approaches. The purpose of the table is to provide a broad perspective from which specific recommendations will be made. A detailed description of the terms used in Table 2.1 is presented in Appendix B.

The above discussion of Table 2.1 identifies information requirements and potential technologies for providing this information. The discussion of technology is broad. The focus, however, is ultimately centered on technology for collecting data that describe the physical condition of buildings and components.

Each of the three decision levels discussed above has distinct information needs that could be satisfied by new or existing technology. At the DGS Level (Level I), an integrated database and database management system would support the DGS management with accessible information covering the full inventory of facilities. Such a system could potentially provide integration of numerical, geographical, and field data, to then be used in combination to support maintenance decisions. This database would also support resource allocation models that optimize installation performance within available resources.

The Building Level (Level II) deals with detailed information concerning building inventory and condition. Field data collection needs at this level are extensive. Commercial database management software used for facility management applications is available at level II. The database used in this software would be expanded to integrate geographical, deficiency images, and field data components. This expansion would enable a wider, more interactive use of the database. The information in such a database could be used to support the operation and maintenance personnel as well as overall management needs. This database could also support models that predict maintenance budgets based on the condition of its components and other supporting data.

The Component Level (Level III) technology is needed to provide accurate, comprehensive condition data for individual components within a building. Technology at this level is component-specific, with the objective of measuring or monitoring a specific physical feature of interest within a component (e.g. area of moisture damage, amount of missing hardware). Data representing these physical features must then be interpreted and the component condition assessed. Computer software plays a vital role in processing data and enabling the data to be entered into the system automatically.

Generally, the higher the decision level, the less detail is needed to support the decision process. Also, the information needs at the various levels can often be satisfied by information collected at the lower level via the appropriate technology. Detailed component information can, in many instances, be additive at the building level and the DGS level.

**Condition Assessment Approach**

Condition assessment is a procedure that uses an inspection process and analysis procedure for determining the condition of a building or group of buildings. The purpose of condition assessment includes the following:

- Developing property files
- Establishing maintenance priorities
- Assessing maintenance backlog
- Preparing maintenance strategies
- Preparing maintenance budgets
- Upgrading property files

Generally, visual approaches are used for data collection for which the condition assessment is made. There are differences between agencies as to what and how much data is collected, and the method or model used for the actual condition assessment. Two basic inspection approaches, though, were found to have at least one of the following ways in common: sampling techniques and comprehensive inspections. In this case, the DGS uses a comprehensive inspection method.

Comprehensive inspections are the most widely accepted form of condition assessment. They assess every building within a facility or institution. However the detail level of comprehensive inspections is determined by an organization's needs and requirements and the intended use of the inspection results. Typically, the inspections collect deficiency information for the major building components (architectural, mechanical and electrical).

Inspection teams vary from trained technicians to architectural or engineering consultants. They typically use inspection checklists to record deficiencies identified for each building component. The inspection team may assign a condition rating to the building components after the inspection; occasionally, the team assigns a building condition rating based on the condition of its components. These condition ratings, however, typically reflect the inspection team's subjective assessment.

A comprehensive inspection procedure for condition assessment of vertical infrastructure (building) systems has been developed. This will be discussed in detail in the next chapter.

**Budget Estimation Approach**

Many unique methodologies have been created to help budget for M&R requirements. These approaches, however, may be categorized according to three common themes: 1) Plant Value Methodologies; 2) Formula-based Methodologies; 3) Life-Cycle Cost Methodologies. Specific models often do not fall neatly into one category but instead represent hybrids of two or more. In VIMS, the approach to estimate maintenance cost is a combination of plant-value and life-cycle cost.

The plant value approach is based on the premise that given an inventory of facilities, M&R costs may be estimated as a function of the construction cost or replacement value of the inventory. Barco (1994) believe it is "one of the more reliable means of correlating facility needs to a budget." One major method defines plant value in terms of the "cost to replace the facility with one of equivalent capacity and function" (Barco, 1994), or "PRV". A unit cost factor (dollar per square foot, $/sf, or dollar per linear foot, $/lf) reflecting recent construction cost experience for a given facility type (office, warehouse, garage, etc.) is multiplied by the existing building's floor area (length or area of pavement, capacity of a central utility plant, length of a utility distribution network, etc.) to determine at that facility's PRV.

The life cycle cost approach attempts to estimate future M&R requirements by breaking down each facility into its system components (electrical, HVAC, roofing etc.) and independently applying life expectancy of life cycle concepts to each system and component. (Melvin, 1992) Life-cycle analysis provides an estimation of required frequencies for preventive maintenance, repair, or replacement. Once expected M&R frequencies are established, task cost data, as from *R.S. Means Square Foot Costs*, can be applied to generate expected funding requirements.

In VISM, nine major systems and four site work systems are suggested. Refer to Chapter 3, Figure 3.1 for further details. Based on the above models, replacement cost for each deficiency will be calculated by multiplying the deficiency area by a specific unit cost factor.

## General Overview of VIMS

To help with vertical infrastructure management, a "Vertical Infrastructure Management System" (VIMS) has been developed. VIMS is defined as the systematic use of engineering technology to determine when, where, and how much to maintain facilities or their components. Generally, these management systems are microcomputer based. Key to the VIMS concept is the structured techniques, procedures, and processes necessary for effective maintenance management. Included in this concept is the need for building or component inspection information. VIMS is a maintenance management decision system with support tools intended to aid in decision-making at building or component levels (Level II and III).

Figure 2.2 presents a schematic dataflow of the system. The entire process is modeled by building data flow diagrams. These diagrams illustrate data flow (arrows), data storage (cylinders), reports (multidocuments), system agents (rounded rectangles) and processes (rectangles). Five major processes are identified in the diagram: 1) Facility Inspection, 2) Update Facility Information, 3) Data Entry, 4) Data Storage, 5) Report Generation. The broken arrows between agents and processes indicate that all processes are

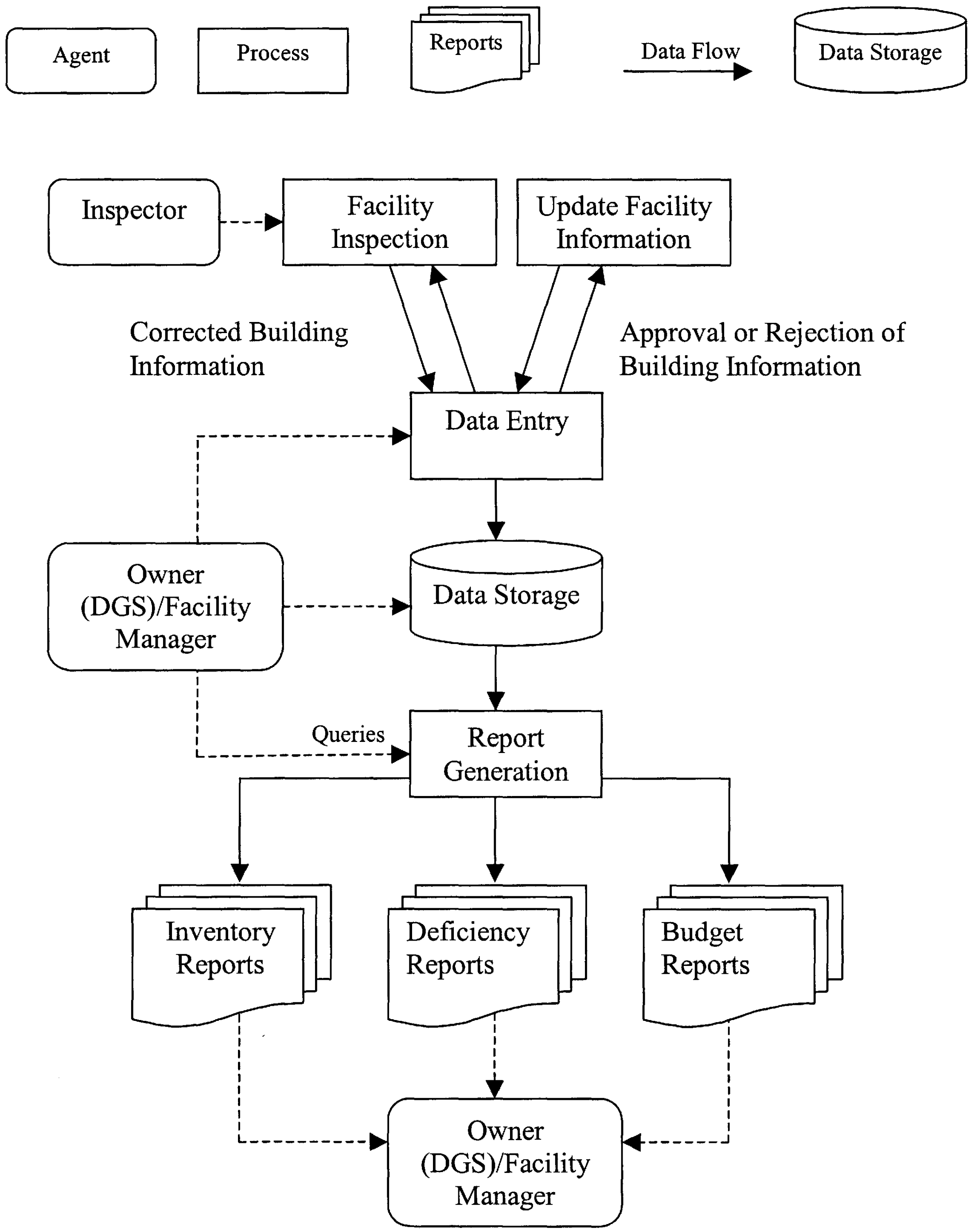



Figure 2.2 Dataflow Diagram for Vertical Infrastructure Management System (VIMS)

performed by certain agents. Verical Infrastructure Inventory and Assessement Database (VIIAD), the database developed by Microsoft Access 97/2000, is the key element of VIMS.

Building data is initially collected on site by inspectors. Before data is entered into the database, the owner or facility manager will validate them by checking if there is redundancy and to see if key information about buildings is included. Key information about a building includes building name, location, gross area, and agency. If some information is missing, inspectors will complete the data forms. When all information is present, the data will be entered into the database. Whether the owners or facility managers need information about a specific building or general review of a big area, they can input their own criteria and then query the database. For example, to know how many buildings in the Des Monies area have poor roofing systems, the facility managers need to enter " Des Moines", "roofing system" and "condition rating lower than D" into the query condition, and then run the query to get the results. The three most often used categories of reports-- inventory, deficiency, and budget-- are already listed in the menu bars. Users can get reports from these three classes without making their own queries.

Table 2.2 Implementation of VIMS Process

| Process | Implementor |
|---|---|
| Facility Inspection | Inspector ( Standard Checklist Forms) |
| Data Entry | Facility Manager (VIIAD) |
| Report Generation | Facility Manager (VIIAD) |

Table 2.2 describes how the major process of developing VIMS is implemented, as well as the agent or computer application responsible for the process and the kind of technology that will support each process. VIMS will provide storage for the facility information and will perform the statistical calculations necessary to produce reports. The system will be administrated by a facility manager from the headquarters (in this case, DGS). Facility managers and inspectors will have access to this system with permission of the DGS. All the data will be collected by inspectors using standard checklist forms, which will be discussed in Chapter 3.

VIIAD, the database previously mentioned in Chapter 1, mirrors the procedure of the reformed facility management; the building is the basic unit of information. The major attributes of each building are name, number, location, agency and general remarks. The building number is an identifier that is used to differentiate among all the buildings in this system. The location is a graphical representation of the building's location in the institution's plans. The agency is the organization to which a building belongs (Capitol Complex, Culture Affairs, Public Safety, Corrections, Human Services, Commerce, or Veteran Affairs). General remarks is a place where inspectors can insert memos about the building. Reports, including inventory reports, deficiency reports and budget reports are essential components of the system.

# CHAPTER 3. CONDITION ASSESSMENT TECHNOLOGY

Generally, a condition assessment encompasses both the collection and analysis of information relating to the physical condition state of the facilities. The specific application must address the purpose of the assessment. A key question to ask is, "What decisions are supported by the condition assessment?" Understanding the decisions to be made will affect the frequency, methodology, and cost of the program.

Assessing condition consists of a number of components, including the timing, frequency and scheduling of data collection (inspection), and the analysis of the collected inspection data. Although this appears to be a straightforward process, condition assessment is quite complex, because there is no single condition assessment approach. Notwithstanding the technical differences in assessing condition between component types in the same building (architectural, mechanical and electrical), condition assessment varies widely within each type. The approach is a function of intended use of the assessment information, available inspection technologies, assessment methodology, and affordability. Thus a tailored condition assessment program that meets agency technical and informational needs at an affordable price is essential if infrastructure management is to be successful. (BRB, 1990)

To perform effective and meaningful maintenance management for Iowa vertical infrastructure, an inspection-based condition assessment procedure was developed which defines the current conditions of building assets. This procedure includes methods to gather, store, manipulate, retrieve, and report inspection and assessment information. The procedure also includes the following concepts:

- Division of the building into components
- Subdivision of components into manageable subcomponents
- Inspection of the subcomponents
- Use of components and building condition indexes
- Database for storing and retrieving information

## Building Components and Subcomponents

Division of buildings into components and subcomponents is essential for (1) identifying major features of a building, (2) identifying areas requiring different inspection skills, and (3) defining dissimilar building areas for M&R planning and work accomplishment.

After reviewing the building component divisions from previous research (J.Rowings, 1994), it is proposed that the VIMS components be divided into 3 top-level divisions and 18 components as shown in Figure 3.1. The tentative VIMS subcomponents are listed in Table 3.1 through 3.4.

## Building Sections

Because of building complexity, use, age, and different material types, subcomponents may not be uniform throughout a building. In addition, a given building subcomponent may occasionally have different functions performance, and M&R

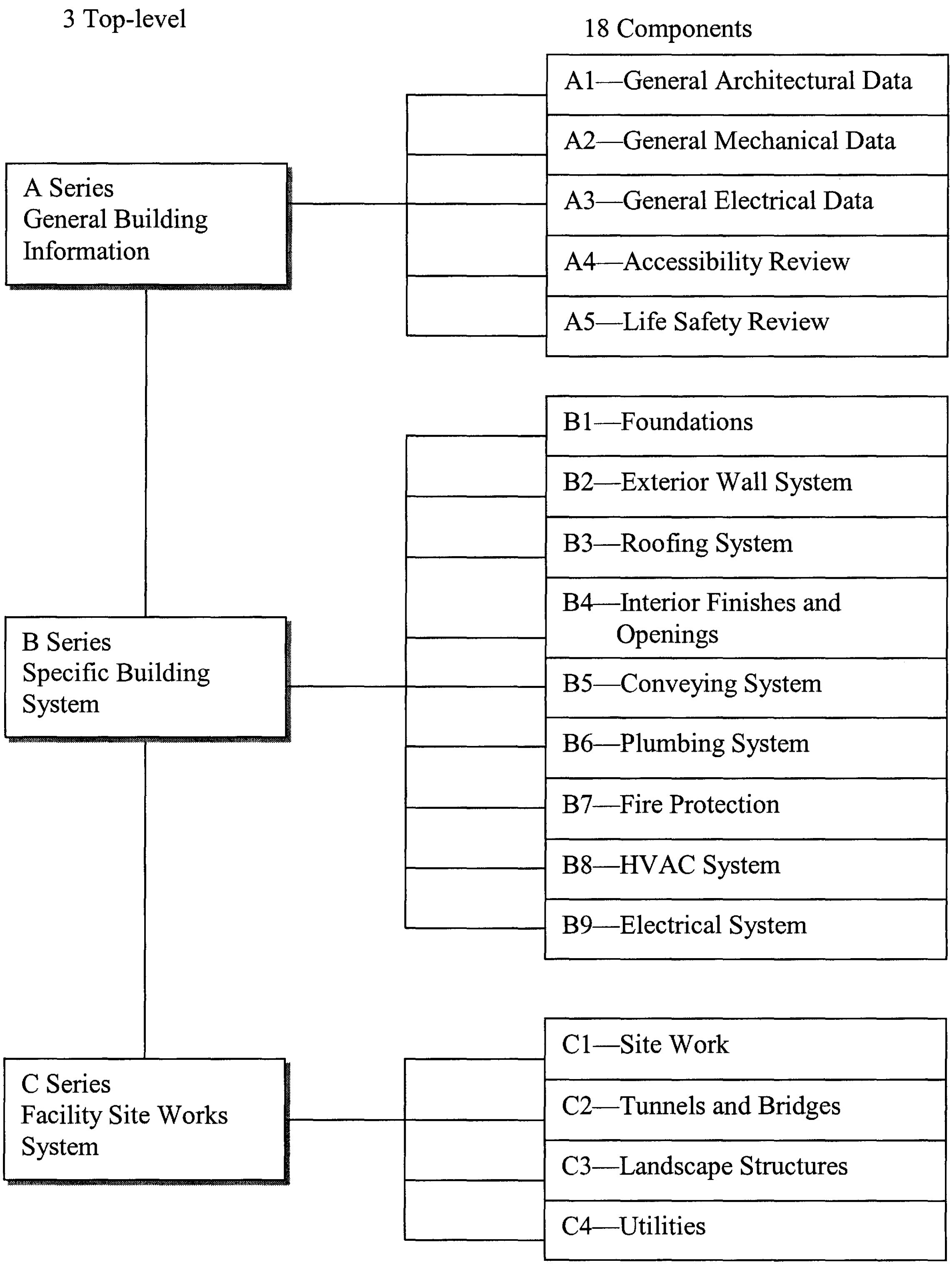



Figure 3.1 VIMS Components

Table 3.1 A Series—General Facility Information

| **A1—General Architectural Data** | **A2—General Mechanical Data** | **A3—General Electrical Data** | **A4—Accessibility Review** | **A5—Life Safety Review** |
|---|---|---|---|---|
| Agency | Overall Rating | Overall Rating | A4.1 Accessible Parking Available | A5.1 Type of Use |
| Building number | Utility Company (Gas) | Electrical System | A4.2 Accessible Path to Building from Parking and Off-Site | A5.2 Exiting |
| Building name | Utility Company (Water) | Electrical Utility Company | A4.3 Passage into Primary Interior Spaces | |
| Location | Control Type | Primary Electrical Characteristics | A4.4 Restrooms | |
| Intended use and current use | Heating Source | Secondary Electrical Characteristics | A4.5 Drinking Fountains | |
| Number of floors | Heating Capacity | Service Size | A4.6 Access to Other than Primary Floor | |
| Gross area | Cooling Source | | A4.7 Interior Stairway Parking and Off-Site | |
| Age | Cooling Capacity | | | |
| Ownership | Water Service Size | | | |

Table 3.2 B Series—Specific Facility System

| **B1—Roofing System** | **B2—Exterior Wall System** | **B3—Roofing System** | **B4—Interior Finishes & Openings** | **B5—Conveying System** |
|---|---|---|---|---|
| B1.1 General Foundation Condition Alignment | B2.1 Masonry Wall | B3.1 Built-Up Roof | B4.1 Flooring | B5.1 Dumbwaiter |
| B1.2 General Structural System | B2.2 Concrete Wall | B3.2 Single Ply Roof | B4.2 Base | B5.2 Elevator |
| | B2.3 Wood Wall | B3.3 Shingles Roofs | B4.3 Interior Wall | B5.3 Escalators/ Moving Walks |
| | B2.4 Metal Wall | B3.4 Metal Roof | B4.4 Finishes & Wall Coverings | B5.4 Material Handling |
| | B2.5 Plaster Wall | B3.5 Flashing, Gravel Stops & Expansion Joints | B4.5 Ceilings | B5.5 Pneumatic Tubes |
| | B2.6 Windows | B3.6 Roof Drains | B4.6 Interior Doors, Frames, Hardware & Windows | B5.6 Other Systems |
| | B2.7 Curtain Wall | B3.7 Gutters & Downspouts | B4.7 Casework | |
| | B2.8 Doors & Frames | B3.8 Skylights | B4.8 Specialty Items | |

Table 3.3 B Series—Specific Facility System (Cont.)

| **B6—Plumbing System** | **B7—Fire Protection System** | **B8—HVAC System** | **B9—Electrical System** |
|---|---|---|---|
| B6.1 Plumbing Fixtures | B7.1 Wet Pipe Fire Sprinkler System | B8.1 Boilers | B9.1 Electrical Services And Distribution |
| B6.2 Water Supply Piping Systems | B7.2 Dry Pipe Fire Sprinkler System | B8.2 Furnaces | B9.2 Lighting And Branch Wiring |
| B6.3 Water Supply Equipment | B7.3 Pre-Action Fire Sprinkler System | B8.3 Other Heat Generation Systems | B9.3 Communication And Security System |
| B6.4 Water Supply Insulation | B7.4 Combination Dry Pipe And Pre-Action Fire Sprinkler System | B8.4 Cooling System | B9.4 Special Electrical Systems |
| B6.5 Sanitary Waste System | B7.5 Deluge Fire Sprinkler System | B8.5 HVAC Distribution System | B9.5 Electrical Controls And Instrumentation |
| B6.6 Storm Water Drainage System | B7.6 Standpipe And Hose System | B8.6 Packaged Terminal A.C. & Terminal Heat Transfer Equipment | |
| B6.7 Special Plumbing Systems | B7.7 Special Fire Protection System | B8.7 HVAC Control And Instrumentation | |
| | | B8.8 Special HVAC Systems And Equipment | |

Table 3.4 C Series—Site Work System

| **C1—Site Work** | **C2—Tunnels And Bridges** | **C3—Landscape Structures** | **C4--Utilities** |
|---|---|---|---|
| C1.1 Drives/Roads/Curbs | C2.1 Pedestrian Bridges | C3.1 Gazebo | C4.1 Site Plumbing Utilities |
| C1.2 Parking Lots | C2.2 Vehicular Bridges | C3.2 Freestanding Deck/Patio | C4.2 Site HVAC Utilities |
| C1.3 Sidewalks | C2.3 Tunnels | C3.3 Storage Shed | C4.3 Site Energy Utilities |
| C1.4 Plazas And Courtyards | | C3.4 Permanent Bench | |
| C1.5 Fencing | | C3.5 Other | |
| C1.6 Athletic Fields And Recreational Areas | | | |
| C1.7 Retaining Walls | | | |
| C1.8 Site Amenities | | | |
| C1.9 Site Drainage/Erosion Control | | | |
| C1.10 Pools/Ponds/Water Features | | | |

requirements associated with particular areas within a building may not the same. For example, the interior finishes of a storage area are likely to be different from those of an office area. Because different areas may have differing M&R needs, and different maintenance costs, it is proposed that the VIMS program will define management units for each building subcomponent. Each subcomponent would consist of at least one section.

Sections can be defined by dividing building subcomponents into logical sections according to the following criteria:

- Location
- Material type
- Age
- Use
- Building type

For example, Figure 3.2 shows how the building sections could be divided according to its geographical location.

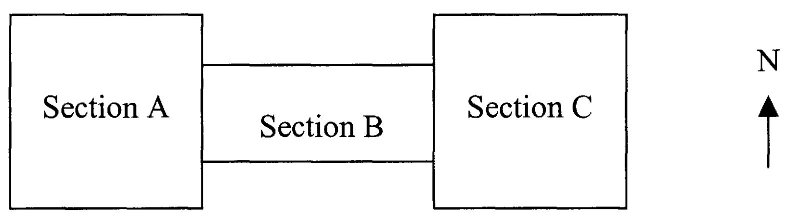



Figure 3.2 Sample Orientation Sketch of a Building

## Inspections

The objective of the VIMS inspection process will be to collect the minimum amount of data required to define both the condition of a building and its components and to develop annual and long-range budgets. To ensure that this is accomplished and to facilitate computer usage, the inspection process must be structured so component deficiencies can be recognized and recorded in a repeatable fashion by trained technical personnel. Each component would be inspected in terms of its subcomponents.

### Inspection Guidelines

Written guidelines, including detailed checklists that show the user which deficiencies to inspect in a building, have been developed. The most commonly used portion of this checklist is included in Appendix A. Inspection checklist forms are needed for each building component and subcomponent. The purpose is to establish a consistent level of inspection detail and ensure that each inspection is comprehensive enough to determine meaningful ratings. The inspection forms must be standardized and structured to permit condition index repeatability. Standardization comes from the specification of certain defect types. The severity, if appropriate, and quantity of each defect type are recorded for the appropriate component and subcomponent on the inspection checklist.

Appendix A discusses facilities in terms of their constituent systems, components and subcomponents. Figure 3.3 is a sample checklist showing specific inspection items. The intent is to list deficiencies that, if found will be corrected by maintenance and repair actions before the next inspection.

| B.4.5 Ceilings | | Photo Key: ________ |
|---|---|---|
| *Condition Rating:* | *Estimated Remaining Life in Years:* | |
| **A B C D F X** | **Indef 20 15 10 5 3 2 1 Unk** | |
| ***Material:*** | ***Deficiency:*** | ***Est. Quantity:*** |
| ☐ Acoustical Tile | B.4.5.1 Stains/Discoloration | ________ |
| ☐ Plaster | B.4.5.2 Peeling/Flaking | ________ |
| ☐ Gypsum Board | B.4.5.3 Settlement/Sagging | ________ |
| ☐ Wood | B.4.5.4 Broken/Missing Units | ________ |
| ☐ Metal Panel | B.4.5.5 Moisture Damage | ________ |
| ☐ Exposed Structure | B.4.5.6 Cracks | ________ |
| ☐ Metal Grid | B.4.5.7 Damaged grid | ________ |
| ☐ Paint | B.4.5.8 Lacking Maintenance | ________ |
| ☐ Stain | B.4.5.9 Other (see Remarks) | ________ |
| ☐ Other ________ | | |
| Remarks: ________ | | |

Figure 3.3 Example Checklist Box (for Ceilings)

**Inspection Frequency**

Generally, infrastructure facilities should be inspected every five years due to high cost of inspections. However, the D or F rating facilities should be inspected annually. The philosophy behind this frequency is that early detection and correction of distresses helps preserve buildings and deter further deterioration. Historical buildings in particular, have increased risk of high maintenance costs because of rapid deterioration of historic features resulting from defects that go undetected. Yearly inspection and repair will aid in preventing any environmental elements from degrading these facilities.

**Inspection Effort**

Optimally, a two-person team is desirable for building inspections. One member of the team should be well versed in civil, architectural, and structural matters, and the other member should be well versed in electrical and mechanical matters. Both members of the team should have a clear understanding and appreciation of building management matters.

## Condition Indexes

There are several approaches of condition assessment that may be used singularly or in combination. The most common approaches include:

- Subjective, based on experience. This is an "ad hoc" approach that has a significant meaning to a very limited audience.
- Standards. Observed distresses are linked to established functionality, safety, or maintenance criteria. Failure to meet the "standard" may result in forced reductions in operations. Standards may have several levels.
- Condition ratings. Similar to standards, the observed deficiencies are compiled into an overall rating on an established rating scale. The scale may have several rating categories.
- Numeric Indexes. Similar to condition ratings, the observed deficiencies are compiled into numeric values within an established range.

Critical aspects of any condition assessment are accuracy, repeatability, and usefulness. These ensure that the results are worthwhile and consistent when derived by different individuals. To accomplish this, clear definitions are needed to describe what the information to be collected. Also, the approached should be as objective as possible. With the exception of the subjective approach, all can be sufficiently accurate, repeatable, and significant to be used in building management.

VIMS uses the combination of standard and condition ratings methods. The VIMS requires inspectors to rate the physical condition of facilities against industry wide standards for that type of building or component. Figure 3.4 shows this five scale rating system.

A—Excellent, which means approximately 95 percent or more of subject building/components are in use and meet the service needs and construction standards. There are very few noticeable defects; component function is not impaired. No immediate work

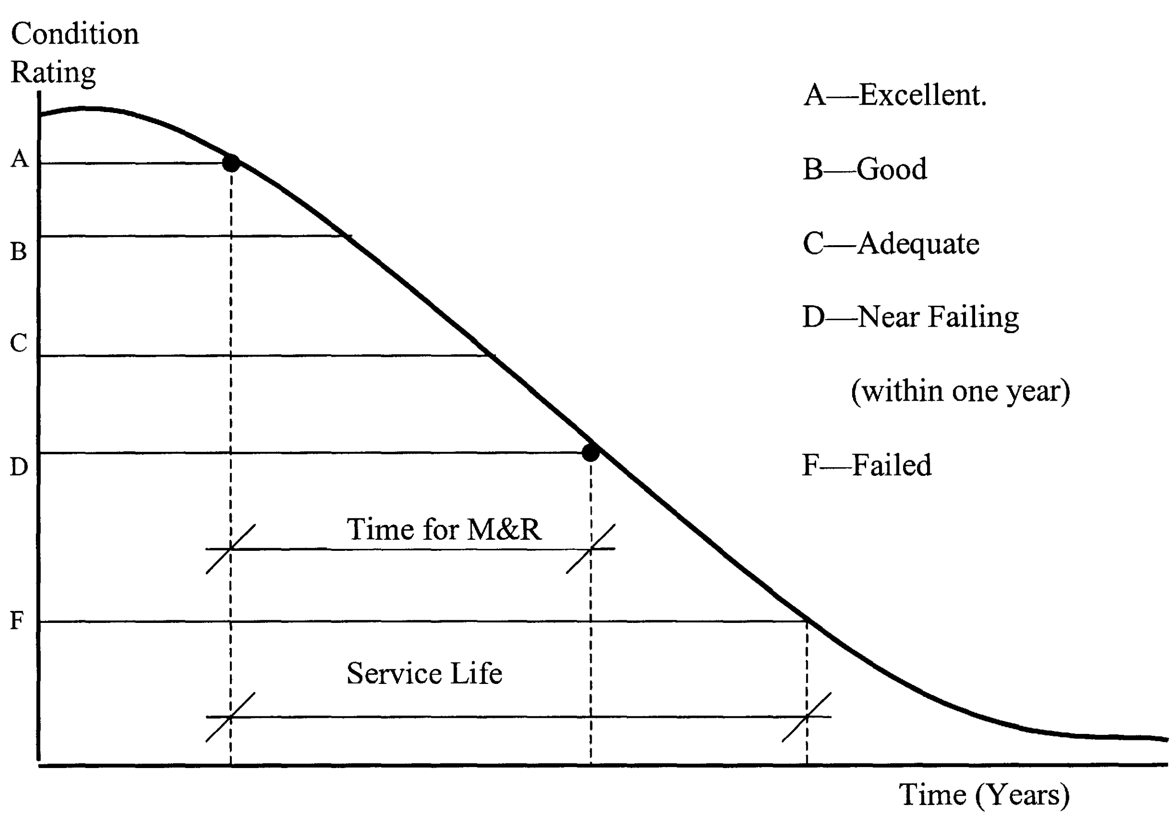



Figure 3.4 Building/Components Performance Curve (Generalized)

action is required, but minor or preventive maintenance could be scheduled. Infrastructure fully support routine performances.

B—Good, which means approximately 85 percent or more of subject building/components are in use and meet the service needs and construction standards. There is only minor deterioration; component function is not impaired. No immediate work action is required, but minor or preventive maintenance should be scheduled. Infrastructure support the majority of routine performances.

C—Adequate, which means approximately 65 percent or more of subject building/components are in use and meet the service needs and construction standard. There is moderate deterioration; component function maybe somewhat impaired. Moderate maintenance or minor repairs maybe required.

D—Near failing, which means less than 50 percent of subject building/components are in use and meet the service needs and construction standards. There is significant deterioration. Component function is so poor that performance is significantly impaired. Major repairs are required.

F—Failed, which means this building/component needs replacement or repair immediately. There is critical deterioration such that the component is barely functional. Major repairs or total replacement are required.

In Appendix A, the inspection checklist includes one more item, X, to represent a code violation in the condition rating list. For example, the door of a building might be in good physical condition, but it violates the National Fire Protection Code or the Life Safety

Code. Therefore, the door needs to be replaced. Since it does not have the same form as the other ratings, the "X" rating is treated separately.

This condition assessment system is well served because it is objective and repeatable, allowing different evaluators to draw similar if not identical, conclusions that lead to appropriate decisions concerning maintenance and repair actions.

The purpose of developing these ratings is to provide a standardized basis for rating current building and component conditions. A single set of rating criteria is envisioned for each component and the building. The heart of the VIMS system is to collect and use current condition information from the inspection checklist form.

## Data Storage and Retrieval

Due to the large number of buildings in the DGS in Iowa, a computer-based data storage and retrieval system is essential to efficient storage, organization, analysis, and reporting of inspection results. The computer database system, which aids in the manipulation of inspection results, including generation of condition indexes, will be discussed in the next chapter. The development of these ratings provides a standardized basis for rating current building and component conditions. A single set of rating criteria is developed for each component and for the building as a whole.

# CHAPTER 4 VIIAD FEATURES

## User Interface Design

VIIAD is a construction engineering management system that will be used by architects, engineers, facility managers, and technical personnel. VIIAD users need to access information quickly in the most direct fashion possible. The navigation capabilities of the system are able to accomplish both objectives. Direct access is provided by toolbar shortcuts and menu selections. (See Figure 4.6) Speed performance is increased by a folder interface style that allows users to access information with only one click of the mouse. In other words, the user interface is task-centered. With this approach, a process is structured around specific tasks that the user wants the system to accomplish.

The prototype is implemented in Microsoft Access 97/2000. Essentially, MS Access is a database management system (DBMS). Like other products in this category, Access stores and retrieves data, presents information, and automates repetitive tasks (such as maintaining accounts payable, performing inventory control, and scheduling). By using Access, one can develop easy-to-use input forms like the one shown in Figure 4.4.

MS Access is also a powerful Windows application; for the first time, the productivity of database management meets the usability of Microsoft Windows. Because both Windows and Access are from Microsoft, the two products work very well together. Access runs on the Windows 95 or Windows NT platform, so all the advantages of Windows are available in Access. Users can cut, copy, and paste data from any Windows application to and from Access. Users can also create a form design in Access and paste it into the report designer.

Using OLE (Object Linking and Embedding) objects in Windows 95 and Microsoft Office 97/2000 products (Excel, Word, PowerPoint, and Outlook), one can extend Access into being a true database-operating environment through integration with these products. With the new Internet extensions, one can create forms that interact with data directly from the World Wide Web and translate his/her forms directly into HTML that works with products like Microsoft Internet Explorer and Netscape Navigator.

Even so, Access is more than just a database manager. As a *relational* database manager, one can have access to all types of data and be able to use more than one database table at a time. It can reduce the complexity of data and make it easier to get jobs done. Access table can be linked with mainframe or server data or use a table created in Paradox or dBASE. It is easy to take the results of the link and combine the data with an Excel worksheet quickly. Since most people use Microsoft Office 97/2000, it is easy to find complete interoperability between Access and Word, Excel, and PowerPoint.

Access is a set of tools for end-user database management. Access has a table creator, a form designer, a query manager, and a report writer. Access is also an environment for developing applications. By using macros or modules to automate tasks, one can create user-oriented applications as powerful as those created with programming languages—complete with the buttons, menus, and dialog boxes (see Figure 4.8 and Figure 4.9). Generally, the power and usability of Access make it, by far, the best database management software on the market today. That is why VIIAD was developed by using MS Access.

The hierarchy chart of a screen's structure for the user interface is presented in Figure 4.1. The screens for the user prototype are shown from Figure 4.2 to 4.10. Figure 4.2 shows the first page of VIIAD. Copyright information and software version can be found from this page. Figure 4.3 gives the "Enter New Data" switchboard, which is similar to "View or Change Data"switchboard. Figure 4.4 shows the data input interface for A-1 form. Figure 4.5 shows general information report of B series (specific building system). This report is also an interactive report, users can use database tools like sort, find, query, and filter to access desired information quickly. Figure 4.6 illustrates the oragnization of the menu bar system of VIIAD. Figure 4.7 and 4.8 give the examples of user friendly interface for generating reports. Figure 4.9 shows the most commonly used budget report that can be customized by by a variety of criteria. Figure 4.10 shows the total estimated cost report by building systems.

**Digital Imaging Technology**

Besides facility inventory data showing the facility type, size and height, age and material types, visual information is also collected during the inspection process. A detailed deficiency image database has been integrated into VIIAD. Information on conditions, such as cracks in walls, water stains, peeling paint, and leaky pipes, is available from this type of image. The images are captured in such a way that the component's relationship to its environment can be understood. This data collection is envisioned as being completed in conjunction with a detailed facilities inventory, which includes a complete walk-through of the facility. During this walk-through each room or space is delineated, and the key components and subcomponents are identified.

Digital cameras used as input devices offer the ability of capturing pictures in digital format. The inspectors can move from room to room in a building, taking digital pictures of deficiencies, and encoding inventory and condition data. Digital pictures can be stored and transferred similar to any other computer file. They can also be enhanced with annotations and/or special marks. The four figures (Figure 4.15, 4.16, 4.17 and 4.18) illustrate three different areas where digital images can provide information by showing a general view of a building, an orientation sketch done by inspectors, and a view of building/component deficiencies. There are more than 50,000 images (over 2.5 GB) stored in VIIAD. These images are stored on optional CD's with hyperlinks in the database, allowing them to be referenced according to the facilities in which they are contained. For example, when one clicks on the "Photo key" field in the General Building Information Report (Figure 4.6), a deficiency picture will appear in a new window corresponding to a specific component. In VIIAD, the photo keys, there are other hyperlinks that allow access to information on building systems, component types or other criteria.

The second key element of digital imaging technology applied in VIIAD is the inspector's orientation sketch (occasionally the inspectors use existing drawings when available). The most efficient and powerful way to use these sketches is to digitalize the images with a scanner and store them in the database.

Integrating the detailed deficiency image and inspector's orientation sketch into facilities inventory provides a means of:

- Enabling experienced inspectors to view problem areas before actual visits.
- Establishing a visual image database of facility and component deficiencies that could be used for current or future condition assessment.

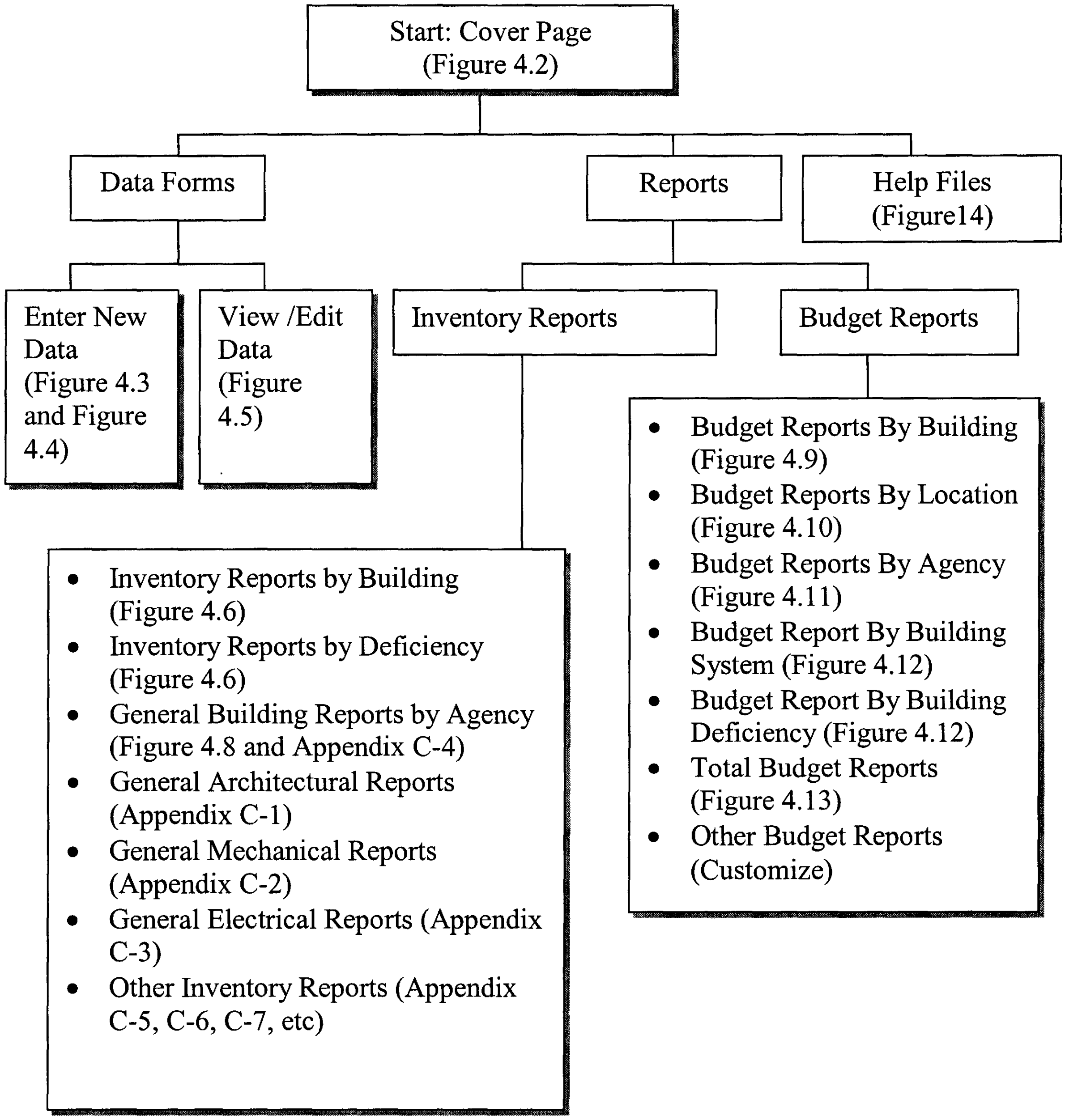



Figure 4.1 Hierarchy Chart of VIIAD's Structure

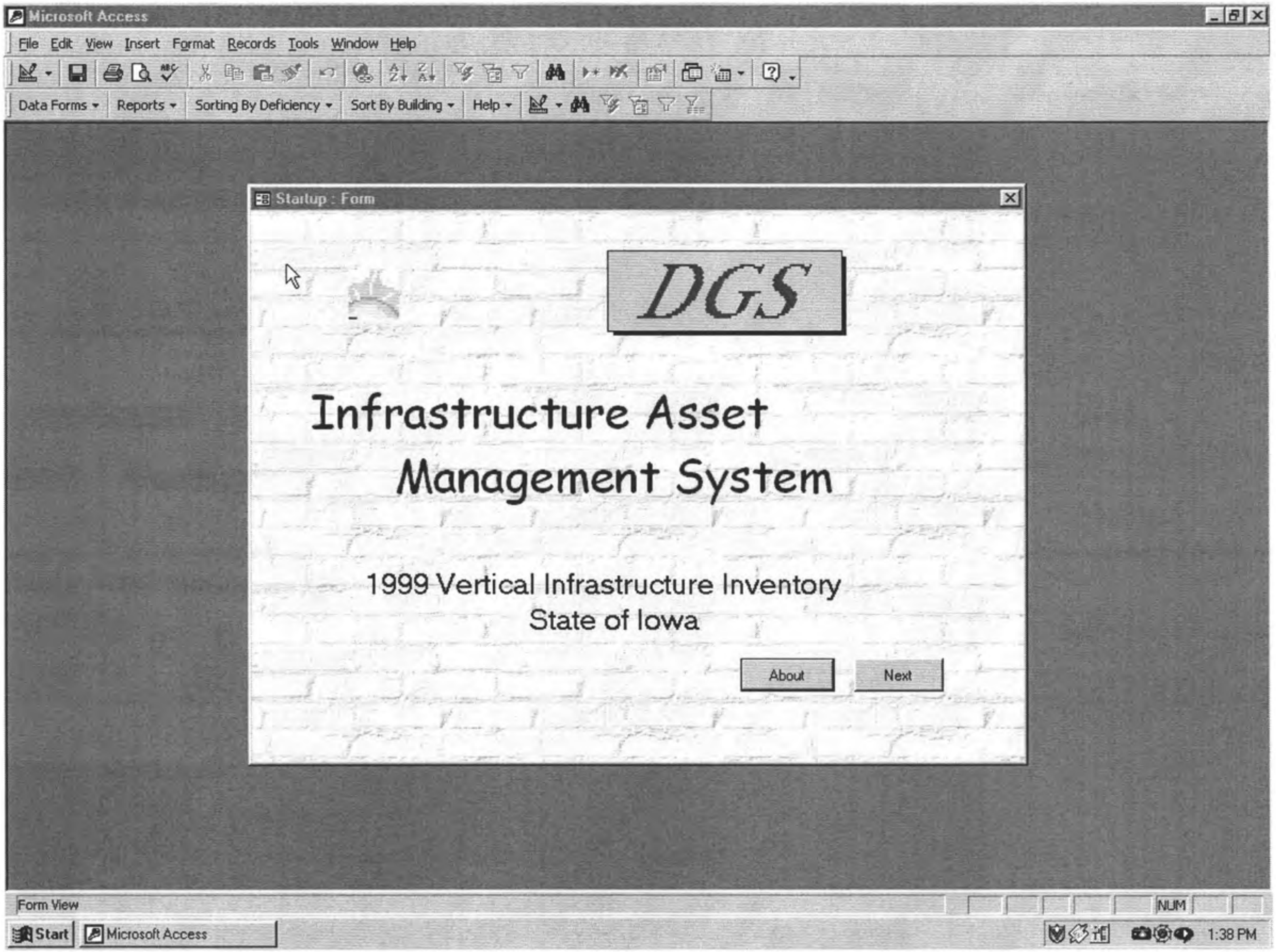



Figure 4.2 Cover Page of VIIAD

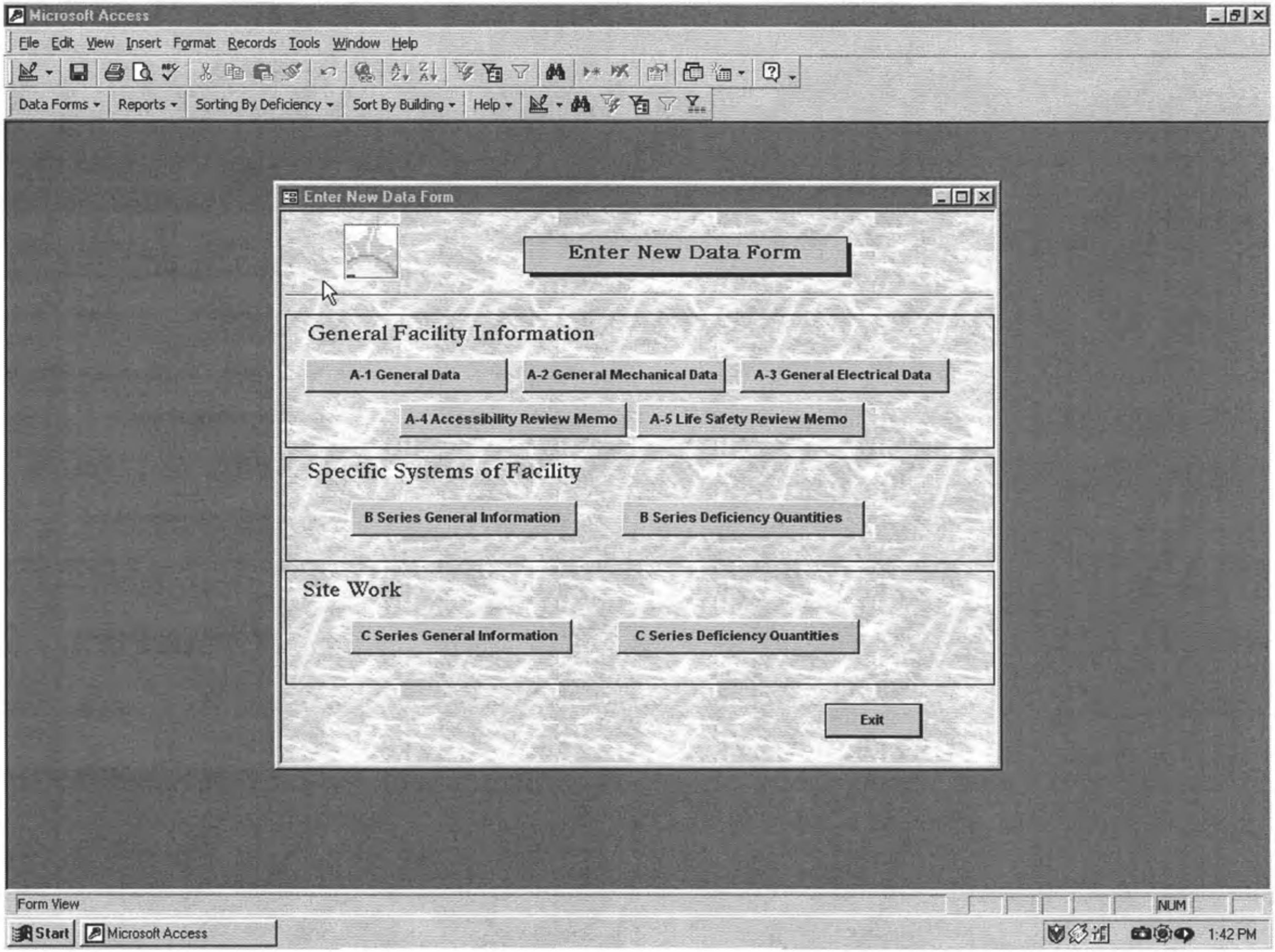



Figure 4.3 Enter New Data Screen

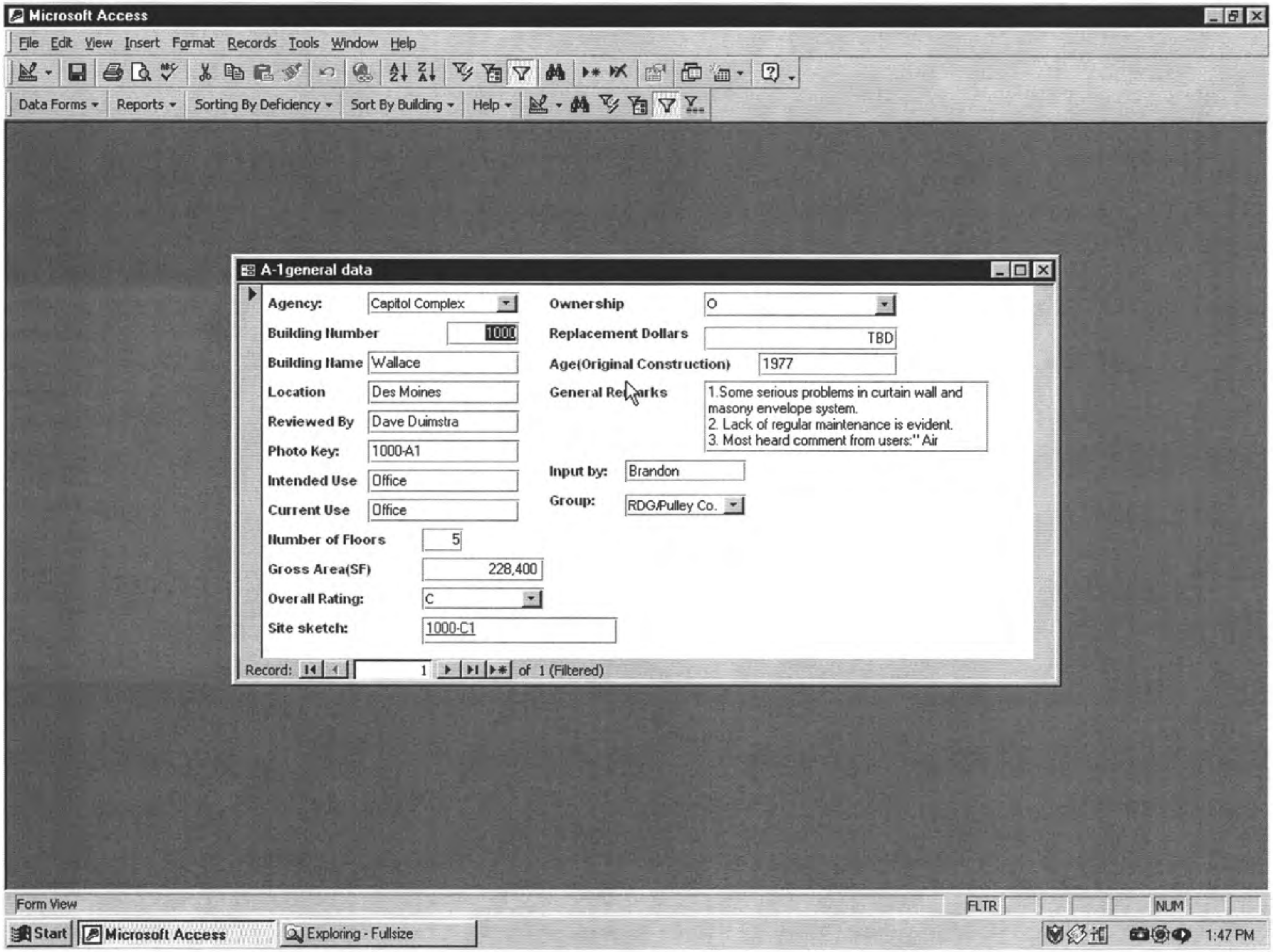



Figure 4.4 Enter New Data to A1-General Building Data Screen

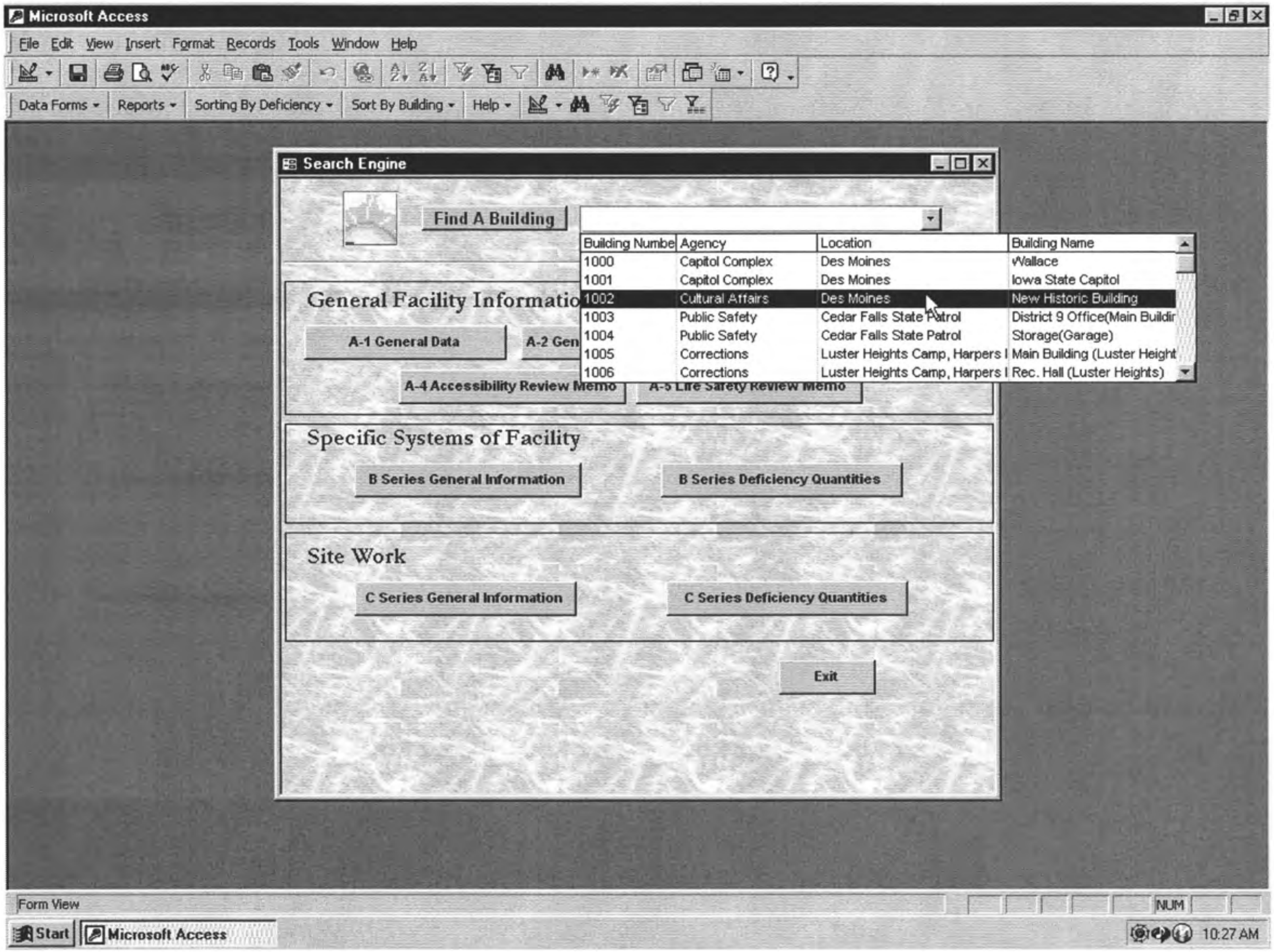



Figure 4.5 View /Edit Data Screen

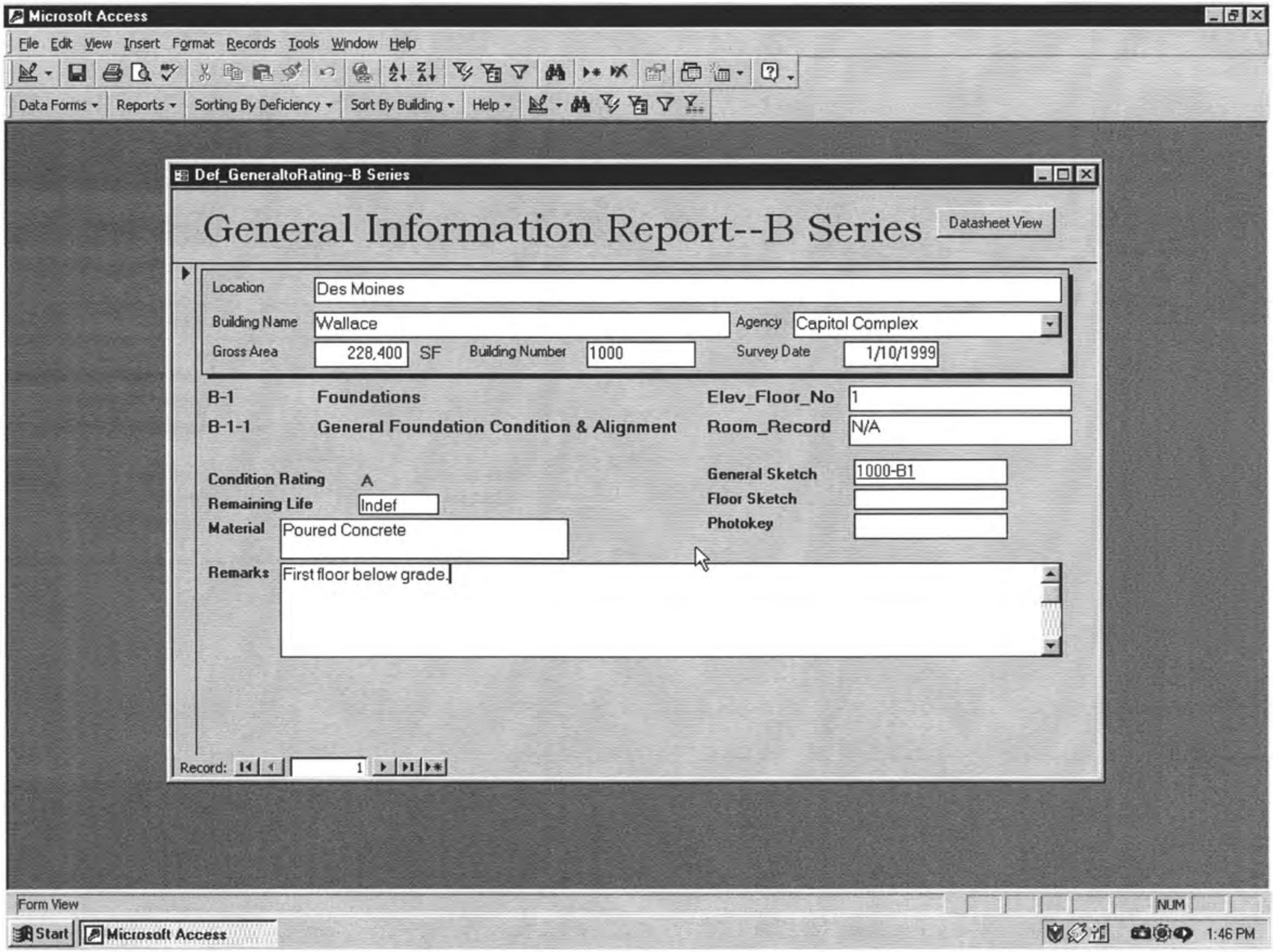



Figure 4.6 General Building Information Report Screen

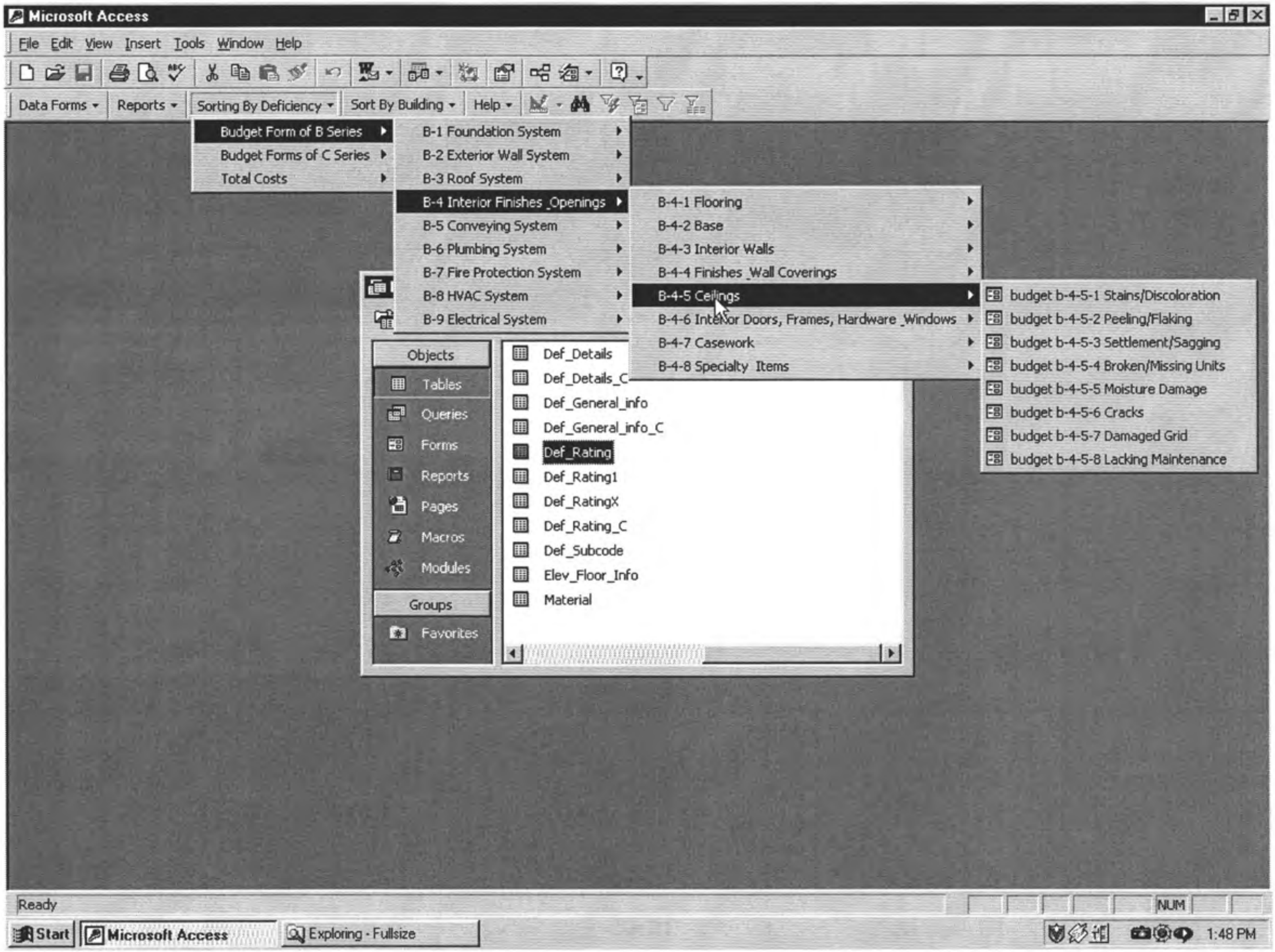



Figure 4.7 Menu and Toolbar Screen

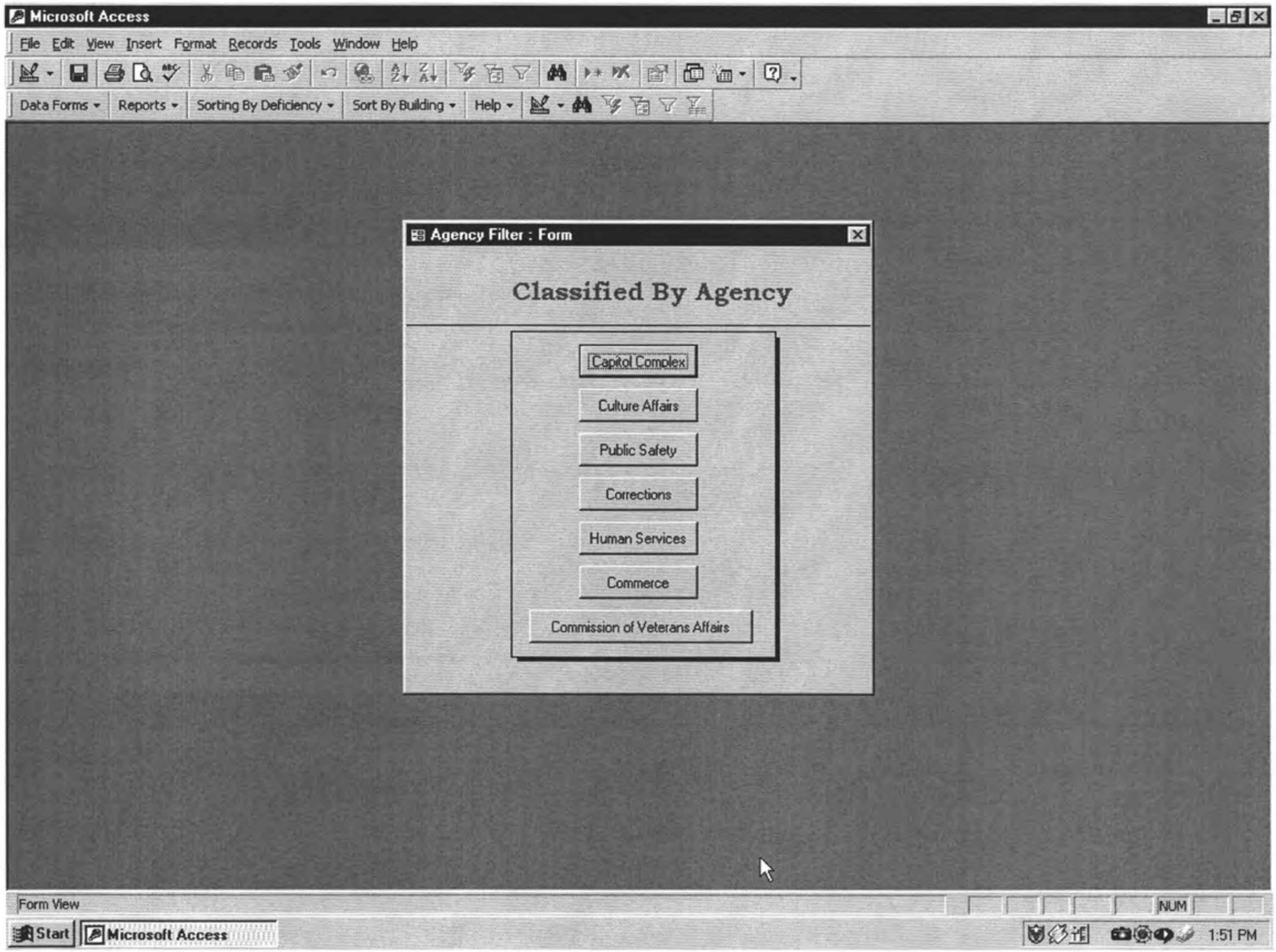



Figure 4.8 Search General Report by Agency Screen

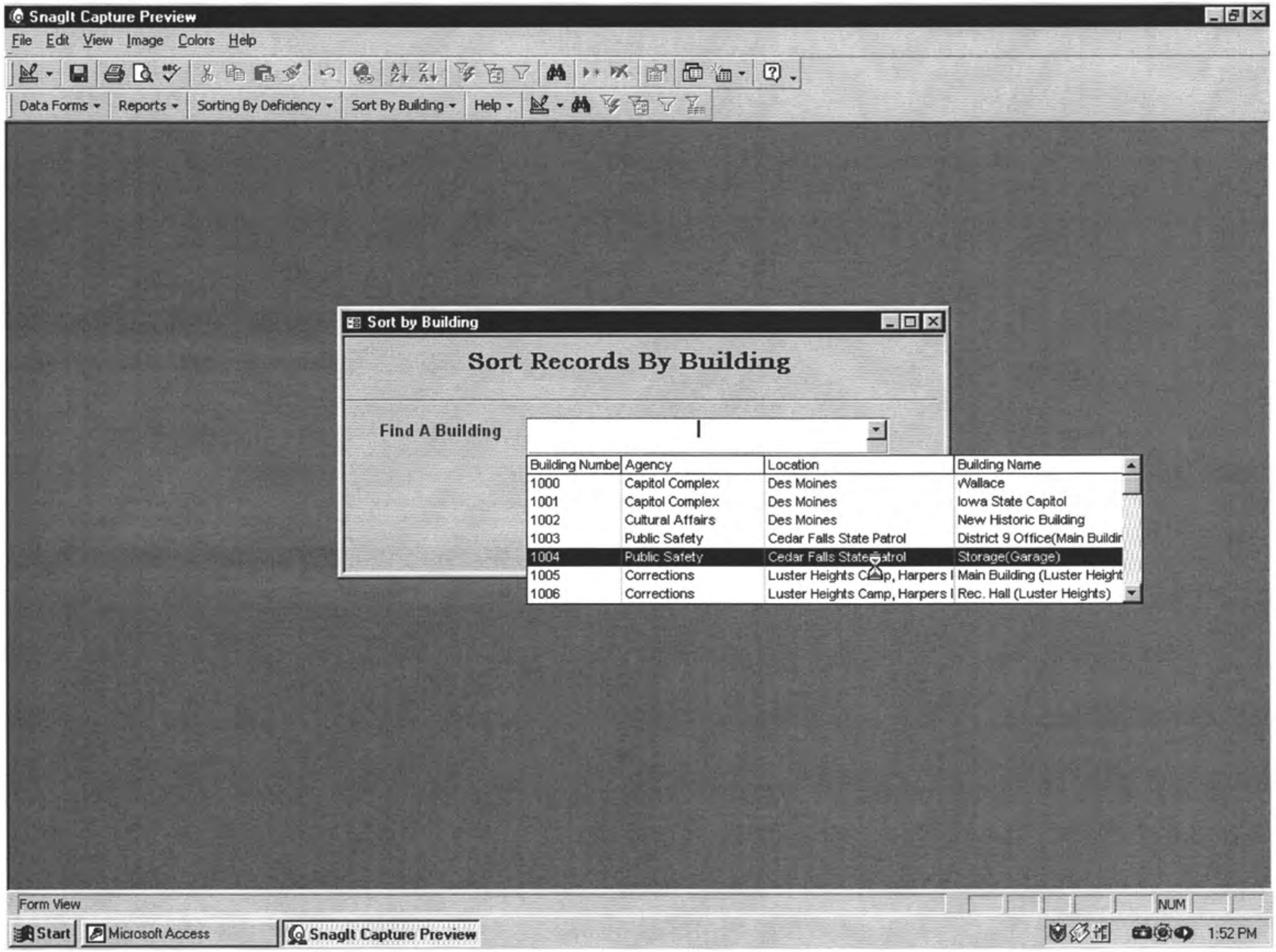



Figure 4.9 Search Building Information by Building Name/Number Screen

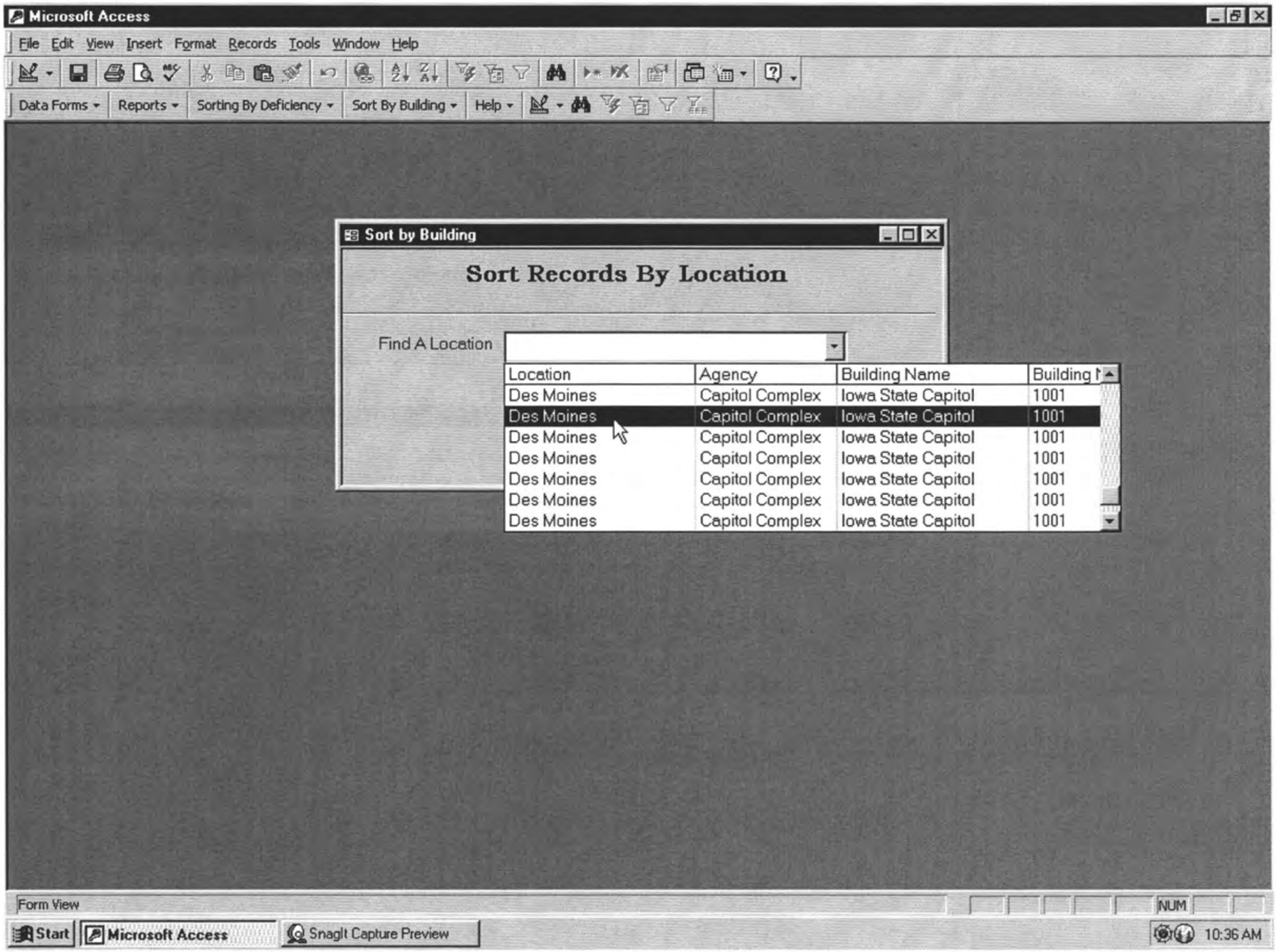



Figure 4.10 Search Building Information by Location Screen

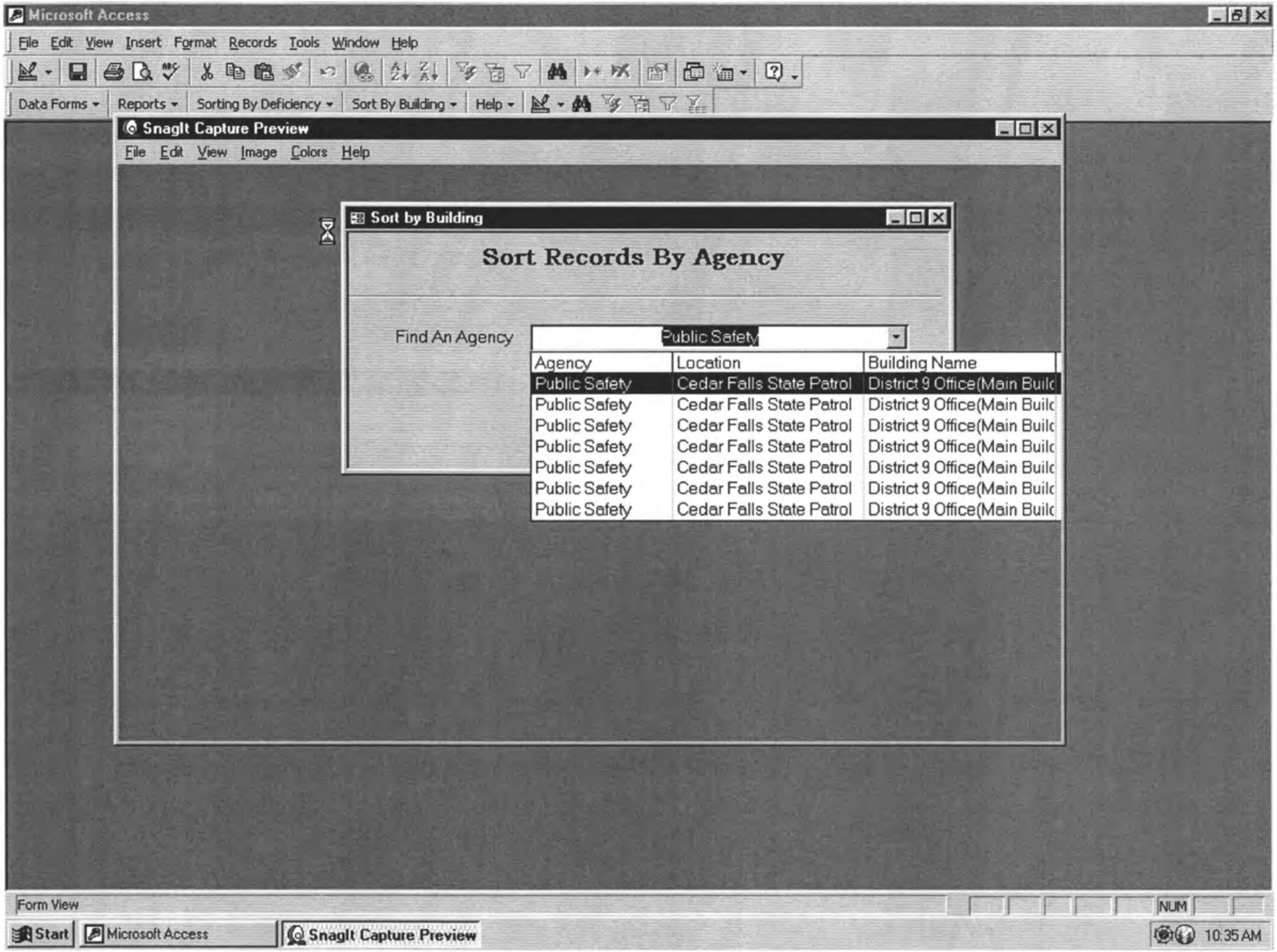



Figure 4.11 Search Building Information by Controlling Agency Screen

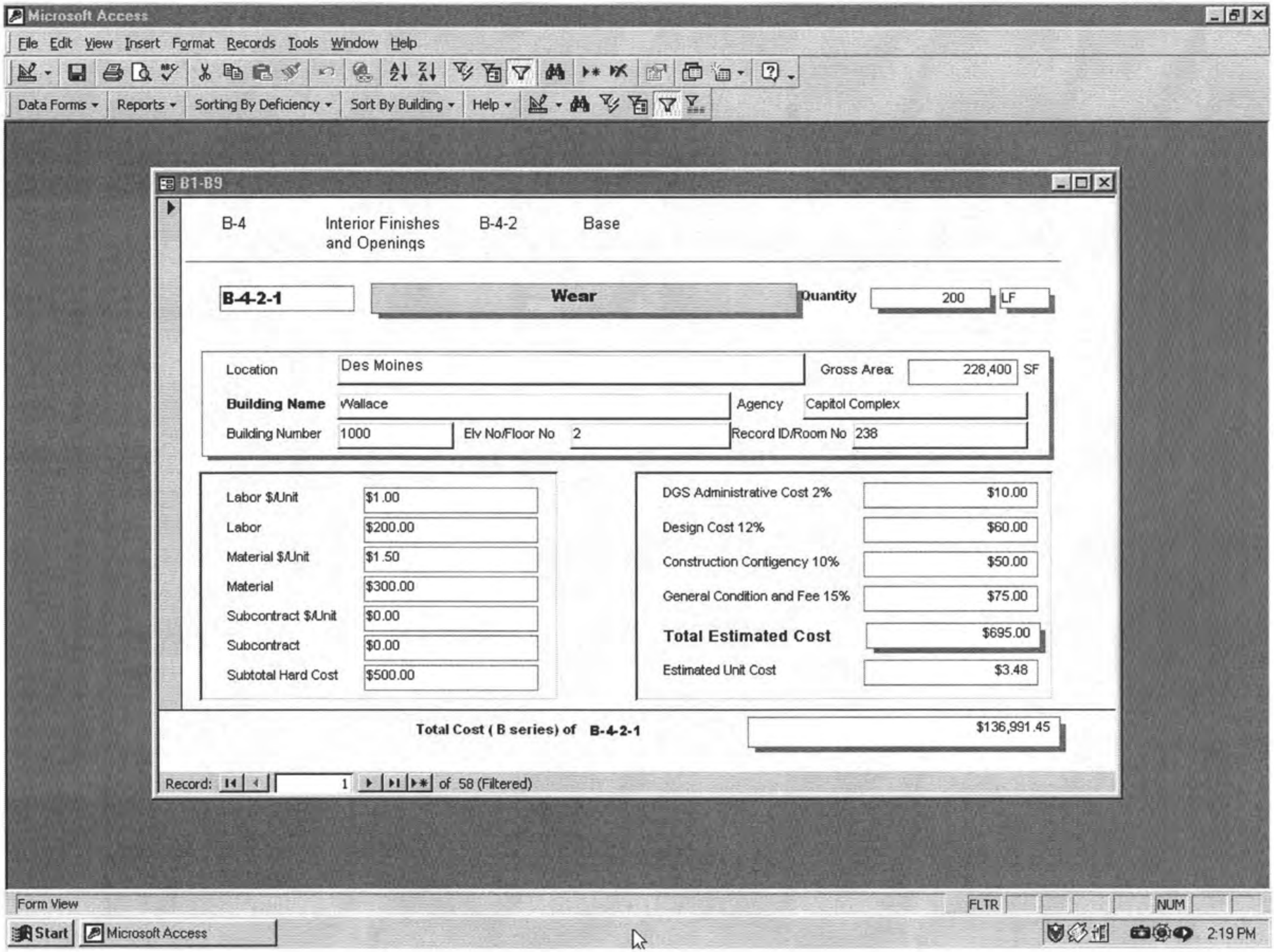



Figure 4.12 Budget Report Screen

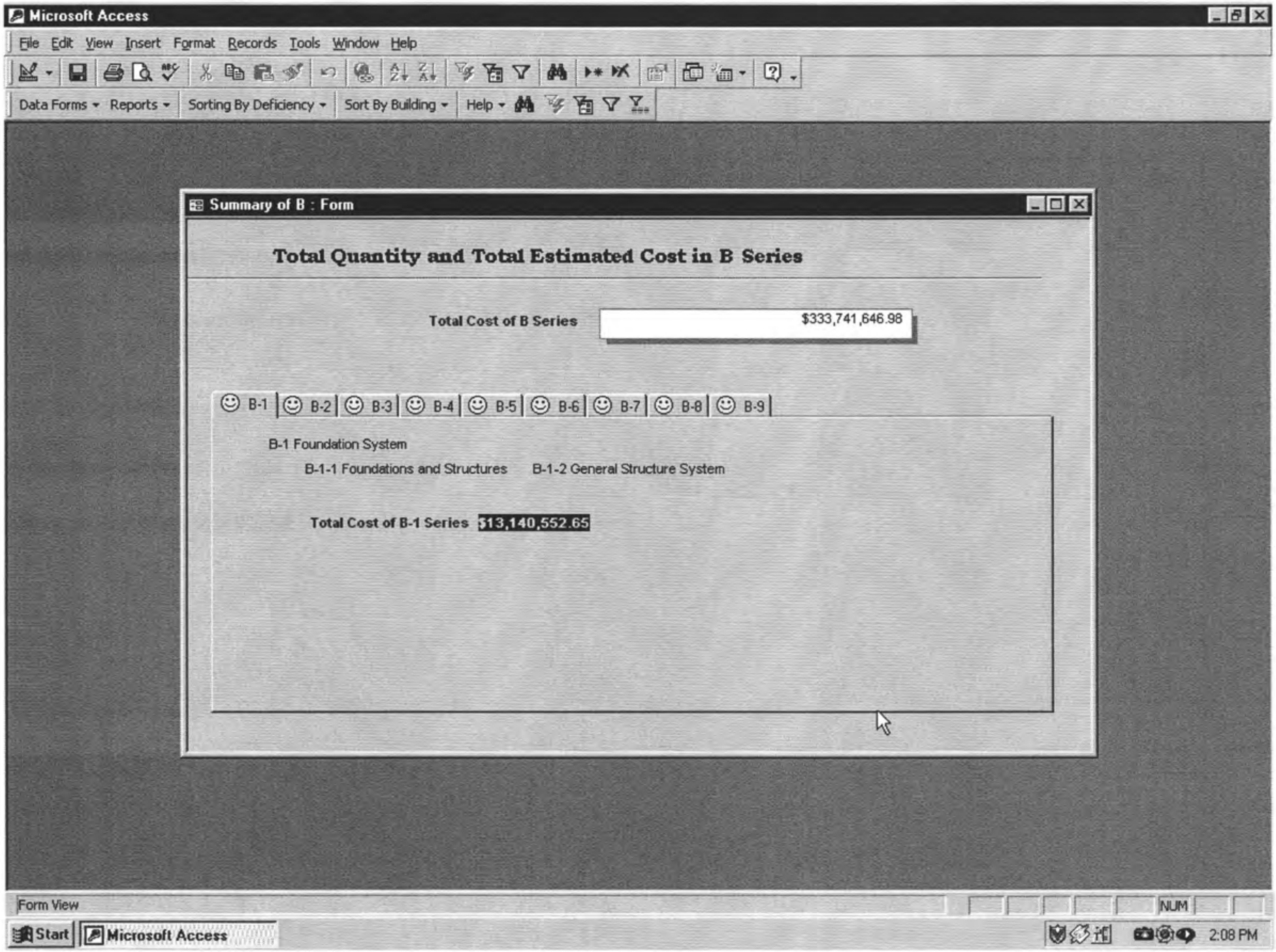
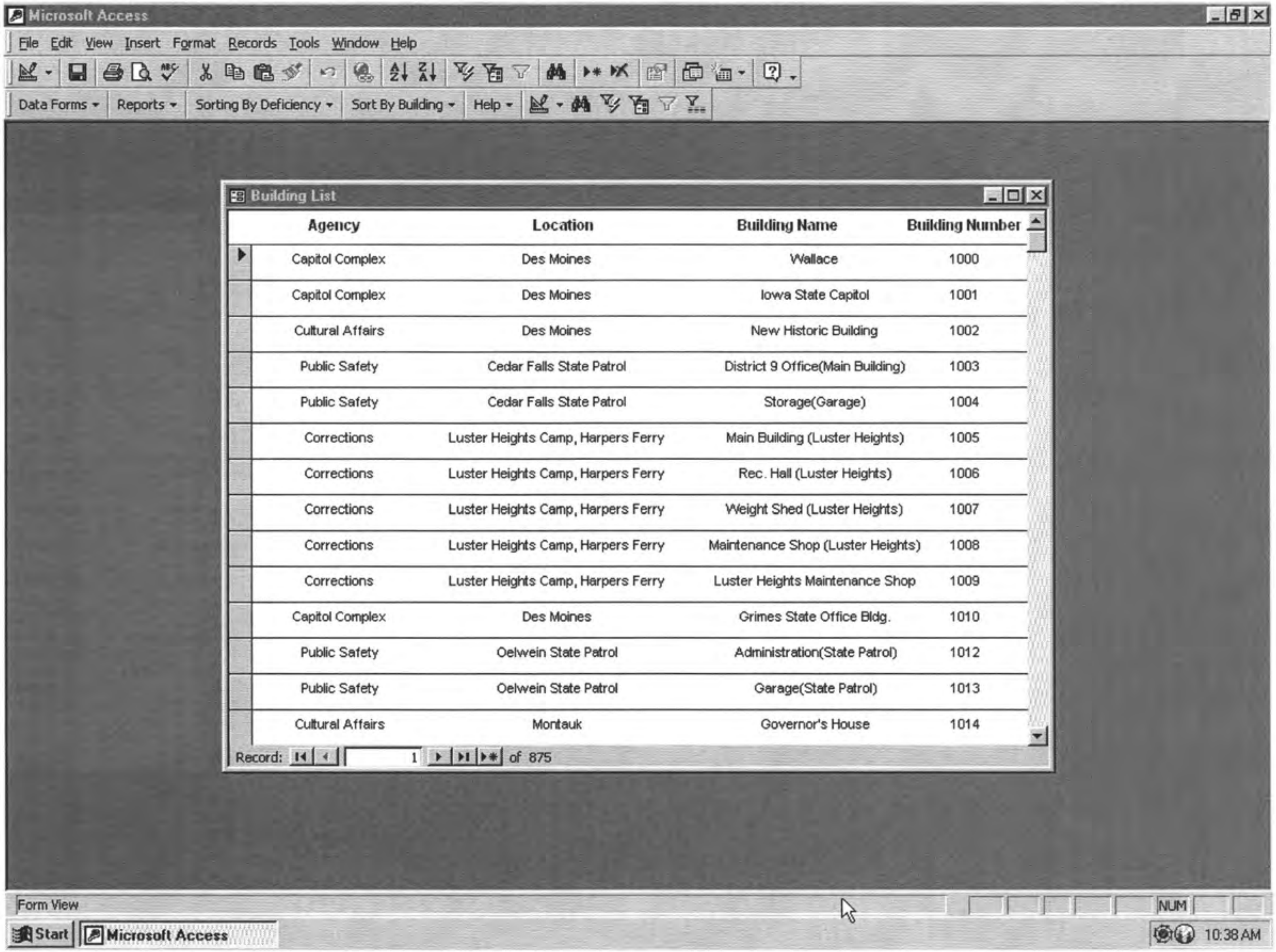



Figure 4.13 Total Budget Report Screen



| Agency | Location | Building Name | Building Number |
|---|---|---|---|
| Capitol Complex | Des Moines | Wallace | 1000 |
| Capitol Complex | Des Moines | Iowa State Capitol | 1001 |
| Cultural Affairs | Des Moines | New Historic Building | 1002 |
| Public Safety | Cedar Falls State Patrol | District 9 Office(Main Building) | 1003 |
| Public Safety | Cedar Falls State Patrol | Storage(Garage) | 1004 |
| Corrections | Luster Heights Camp, Harpers Ferry | Main Building (Luster Heights) | 1005 |
| Corrections | Luster Heights Camp, Harpers Ferry | Rec. Hall (Luster Heights) | 1006 |
| Corrections | Luster Heights Camp, Harpers Ferry | Weight Shed (Luster Heights) | 1007 |
| Corrections | Luster Heights Camp, Harpers Ferry | Maintenance Shop (Luster Heights) | 1008 |
| Corrections | Luster Heights Camp, Harpers Ferry | Luster Heights Maintenance Shop | 1009 |
| Capitol Complex | Des Moines | Grimes State Office Bldg. | 1010 |
| Public Safety | Oelwein State Patrol | Administration(State Patrol) | 1012 |
| Public Safety | Oelwein State Patrol | Garage(State Patrol) | 1013 |
| Cultural Affairs | Montauk | Governor's House | 1014 |

Figure 4.14 Example Help File (Building List) Screen

Figure 4.15 Overview of a Building

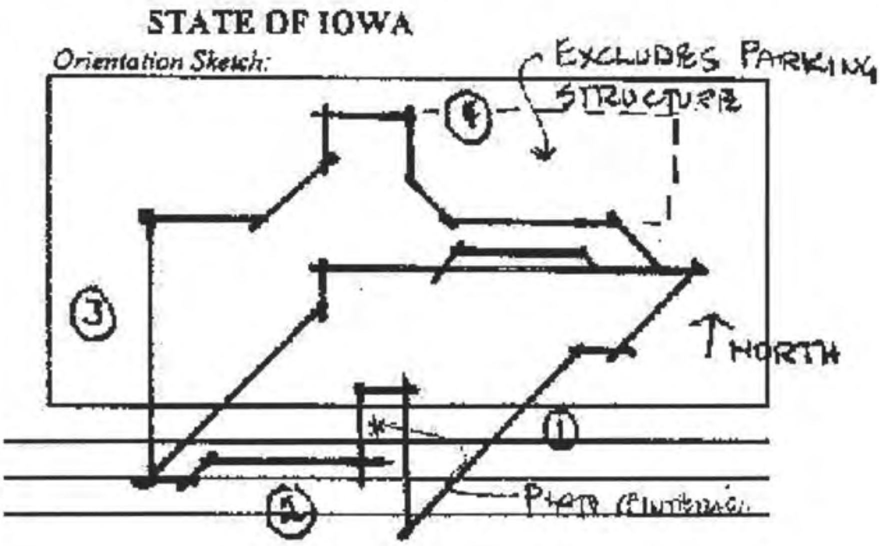



Figure 4.16 Orientation Sketch of a Building

Figure 4.17 View of a Deficiency on Exterior Wall

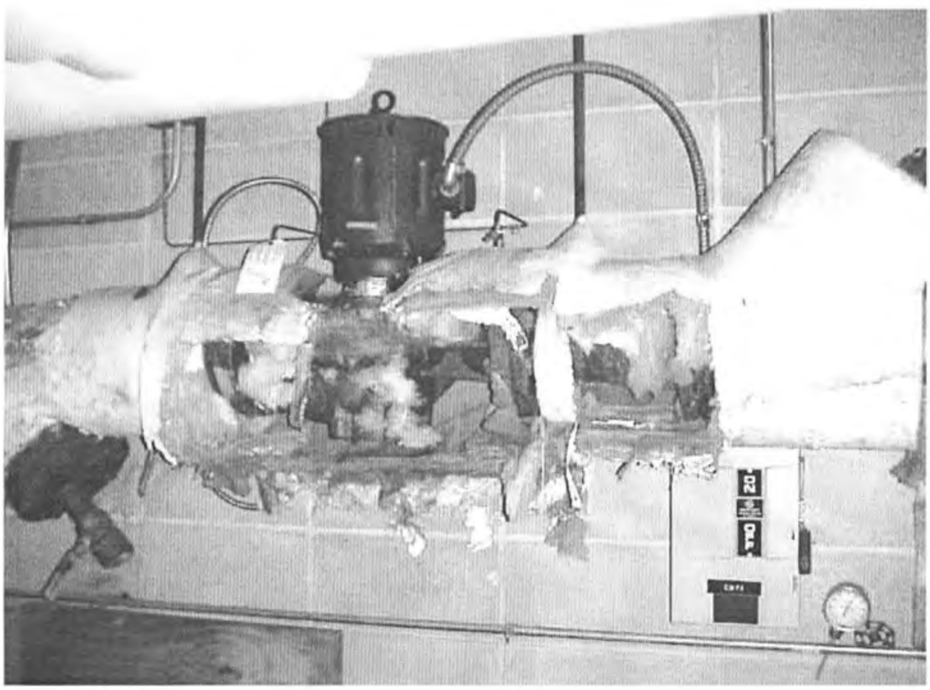


Figure 4.18 View of a Deficiency on HVAC system

- Allowing operations staff to actually "see" the components or subcomponents when they are going on a service call.
- Creating a permanent record of how an item or area looked on a specific date to aid in project documentation and justification.
- Allowing estimations and planning functions to be performed at the DGS level, with the complete facilities database available to the estimator for reference.

Digital imaging technology applied in VIIAD allows for speed and efficiency when accessing images; it also enables numerical data associated with the images to be used for many applications.

## Database Reporting

The reporting capabilities are the most visible part of VIIAD. Since the usefulness of the survey effort is closely linked to the quality of the reporting capabilities. Design and implementation of reports was of primary importance. There are more than 150 reports, which vary from Word format information collections to sophisticated charts, which graphically depict the infrastructures inventoried.

Infrastructure reports can be divided into three major categories:

1. Inventory Reports (refer to Figure 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9)

- General facility reports for architectural, mechanical, and electrical areas (See Appendix C)
- General accessibility reports (See Appendix C)
- General inventory reports listed by building, agency, location (See Appendix C)

2. Deficiency Reports (refer to Figure 4.6)

- General deficiency reports listed by specific area or deficiency (e.g. by B-1 Foundation or by B-4-3-1 Stains or Discoloration.)
- General deficiency reports listed by building, agency, or location

3. Budget Reports (refer to Figure 4.9, 4.10,4.11,4.12,4.13)

- Specific maintenance or repair budget listed by deficiency, location, building, agency. (See Figure 4.9,4.10,4.11,4.12)
- Total maintenance or repair budget (See Figure 4.13)

A report may fit into more than one category. As shown in Figure 4.12, the "Budget Report by Building" can also be used as a deficiency report because it gives quantity, location, and the deficiency name for a specific building. By applying simple database tools, such as sorting or filtering, deficiency reports for a specific building or location can also be generated.

## Quick Budget Plan Function

VIIAD uses the Applied Management Engineering (AME) process to estimate maintenance cost. This modeling package was introduced by AME and Rush (1991). According to AME, long-term replacement needs are estimated through a combination of condition assessment and system life cycle concepts in a six-step process:

1. Categorize the types of facilities in the inventory.
2. Establish unit costs for system repair/replacement within each category.

3. Develop a list of replaceable components: Foundations, Roofs, Exterior Walls, HVAC, etc.
4. For each component class, list all construction methods or material types present. Different materials will yield different life expectancies and replacement costs.
5. Determine the unit replacement cost for each D or F rating component.
6. Apply a process of "rolling up" such that subcomponents' replacement costs are used to calculate component, system, and finally a building-level cost.

Through this process, facility components are assessed, and the remaining useful life is estimated. Years to replacement are estimated in five-year increments. (More precise estimates are considered unrealistic). By comparing remaining life with the projected life cycle of each component, the replacement period and associated cost can be determined.

Table 4.1 shows a cost estimate worksheet for a typical repair project. Rows 1 through 10 show the specific deficiency information, presenting the exact location of the deficiency and how cost of each component required repair the deficiency. Labor price (row 11) comes from multiplying quantity (row 10) by unit labor price (refer to Table 4.2). In this example, the unit price is $10.00/sf, and the quantity of this deficiency (glass breakage) is 20 square feet. The labor cost is calculated as $200.00. The same process is completed for material and subcontract costs with their corresponding unit prices. The subtotal hard cost is the sum of labor, material and subcontract costs. In row 15 through 18, DGS administrative cost, design cost, construction contingency and general conditions and fees are shown as a percentage of the subtotal hard cost. These percentages are 2%, 12%, 10% and 15%, respectively. The total estimated cost will be the sum of the four overheads costs above and the subtotal hard cost. The estimated unit cost for this specific deficiency will be the total estimated cost divided by its quantity.

## Security and Control Design

The construction inspection process is highly decentralized. Only the system owner (DGS) and facility manager have access to the entire system. All other users have access only to information for the buildings they are in charge of maintaining.

VIIAD includes the following security features:

1. Access Controls:

- Each user will have a username and password to access the database.
- Users will only be able to access specified information based on their username
- Access will be terminated when the user terminates the relationship.
- The system will prompt the user for a password update every month or as desired.

2. Data Input:

- Users will only have access to read or create to the database.
- Some fields will be locked to protect against data input errors.
- Validation rules will be used to assure data accuracy.
- Default values will be used where possible to minimize data entry errors.

3. Processing Validation:

- Batch transmission will be validated by feedback confirmation.
- Each inspection file will be referenced by an operator ID.

Table 4.1 Replacement Cost Estimate Worksheet

| No. | Items | Building Info. |
|---|---|---|
| 1 | Agency | Capitol Complex |
| 2 | Location | Des Moines |
| 3 | Building Name | Wallace Building |
| 4 | Building Number | 1000 |
| 5 | Floor Number | 1 |
| 6 | Room Number | 101 |
| 7 | Deficiency ID | B-2-6-2 |
| 8 | Descriptions | Glass Breakage |
| 9 | Unit | SF |
| 10 | Quantity | 20 |
| 11 | Labor | $200.00 |
| 12 | Material | $200.00 |
| 13 | Subcontract | $200.00 |
| 14 | Subtotal Hard Cost | $600.00 |
| 15 | DGS Administrative Cost | (2%) $12.00 |
| 16 | Design Cost | (12%) $72.00 |
| 17 | Construction Contigency | (10%) $60.00 |
| 18 | General Conditions and Fees | (15%) $90.00 |
| 19 | Total Estimated Cost | $834.00 |
| 20 | Estimated Unit Cost | $41.70 |

Table 4.2 Sample Unit Price Table

| Items | Descriptions | Unit | Labor $/Unit | Material $/Unit | Subcontract $/Unit |
|---|---|---|---|---|---|
| B-2-6-1 | Frame/Sash Deterioration | EA | $210.00 | $210.00 | $210.00 |
| B-2-6-2 | Glass Breakage | SF | $10.00 | $10.00 | $10.00 |
| B-2-6-3 | Missing Hardware | EA | $21.00 | $105.00 | $0.00 |
| B-2-6-4 | Malfunctioning Hardware | EA | $21.00 | $105.00 | $0.00 |
| B-2-6-5 | Putty Failure | LF | $6.00 | $0.00 | $11.00 |
| B-2-6-6 | Sealant Deterioration | LF | $6.00 | $0.00 | $11.00 |
| B-2-6-7 | Lacking Maintenance | SF | $0.00 | $0.00 | $0.00 |

- Processing of the same data concurrently will not be allowed.

4. Data Backup:

- A full data backup system will be necessary to safeguard the data stored.
- Backups will be performed at the server location.
- Backups will update only new data or data that has been changed.
- Backups will be tested and CDs will be alternated.

## VIIAD Applications

VIIAD can be applied in almost all aspects of facility management. In terms of the problem statement of vertical infrastructure management needs mentioned in chapter 1, the three key problems for FM are 1) Inventory, 2) Maintenance budget, and 3) Condition Assessment. VIIAD can greatly assist facility owners or managers in fixing these problems in three areas.

First, VIIAD has various inventory reports, some are listed in appendix C and some exist as interactive reports in the database. For example, users can go from the "Enter/Review Data" menu (see Figure 4.3) to review building information. Figure 4. 19 and Figure 4.20 are two graphical reports of general inventory information. Figure 4.19 shows vertical infrastructure gross area summarized by agency. Figure 4.20 illustrates the distribution of public buildings by agencies.

Second, VIIAD contains various maintenance budget reports. Users can sort interactive reports by a building name, a specific deficiency, or a building system. For

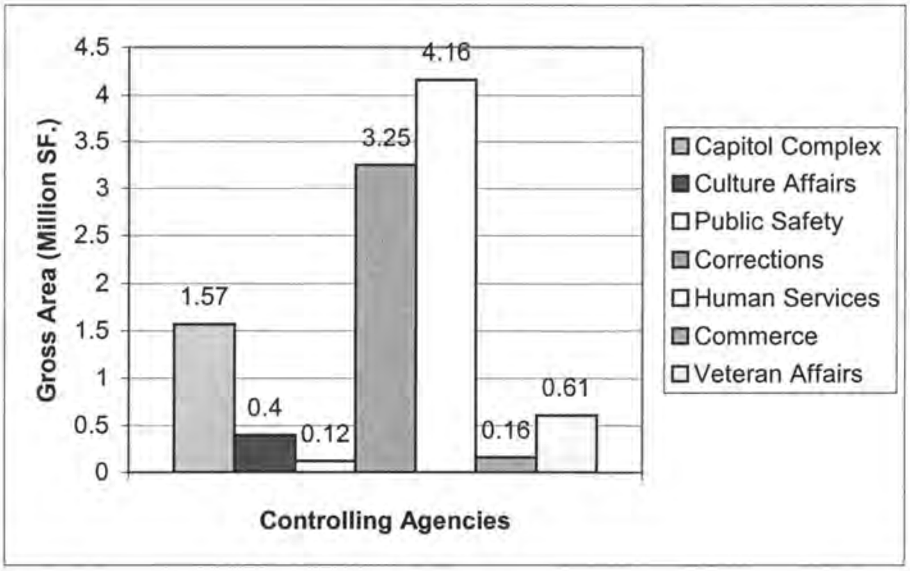



Figure 4.19 Vertical Infrastructure Gross Area By Agency

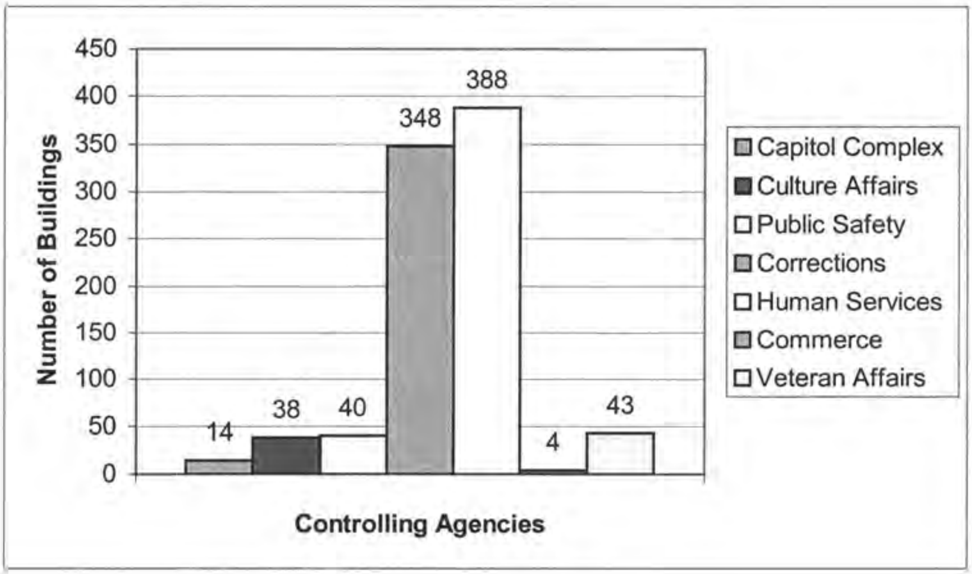



Figure 4.20 Building Number Distribution by Agency

example, Table 4.3 presents the overall budget plan of the whole system. "B-8 HVAC System" and "C-2 Tunnels and Bridges" are the two system with the largest maintenance needs. Table 4.4 is a budget plan for the Wallace building in Des Moines. This building requires maintenance on "B-8 HVAC System," which makes up 78.5% of the total maintenance cost for this building. Similar reports can be easily retrieved for any building in this database.

Third, VIIAD has condition reports that assign a rating for all components and subcomponents of each building. Figure 4.21 presents the overall building conditions of vertical infrastructure of the State of Iowa. Most public buildings are in "Adequate"

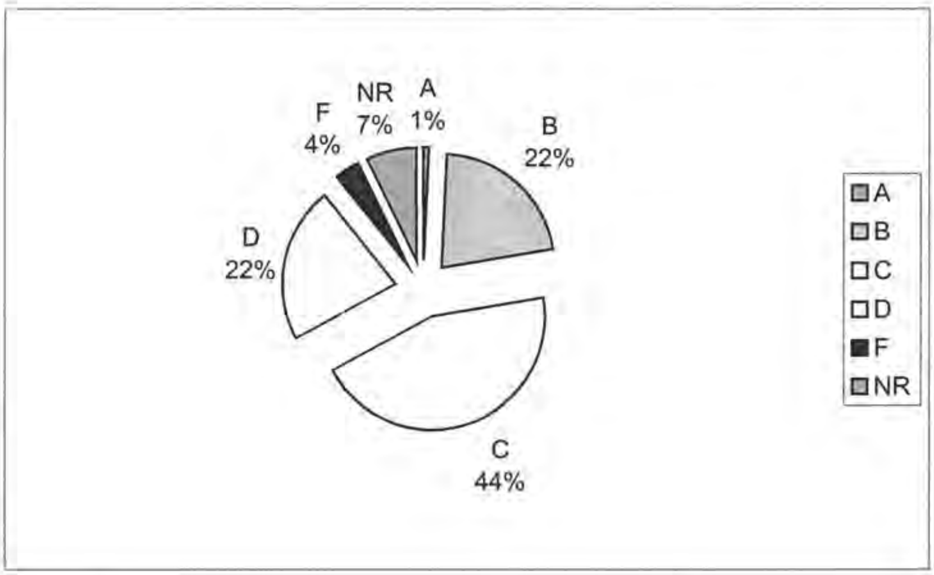



Figure 4.21 Overall Building Condition Distribution in the State of Iowa

Table 4.3 Budget Plan by Building Systems

| Overall Building Systems | Budget Plan (Mil. $) | Percentage |
|---|---|---|
| B-1 Foundations | $13 | 2.46% |
| B-2 Exterior Wall Systems | $70 | 13.26% |
| B-3 Roofing Systems | $6 | 1.14% |
| B-4 Interior Finishes and Openings | $16 | 3.03% |
| B-5 Conveying Systems | $0.7 | 0.13% |
| B-6 Plumbing Systems | $58 | 10.99% |
| B-7 Fire Protection Systems | $0.8 | 0.15% |
| B-8 HVAC Systems | $116 | 21.97% |
| B-9 Electrical Systems | $53 | 10.04% |
| C-1 Site Work | $60 | 11.37% |
| C-2 Tunnels and Bridges | $116 | 21.97% |
| C-3 Landscape Structures | $0.4 | 0.08% |
| C-4 Utilities | $18 | 3.41% |
| **Total** | **$527.9** | **100%** |

Table 4.4 Building Budget Plan for Wallace Building

| Building Systems | Budget Plan | Percentage |
|---|---|---|
| B-1 Foundations | $834 | 0.01% |
| B-2 Exterior Wall Systems | $893,075 | 7.52% |
| B-3 Roofing Systems | $0 | 0.00% |
| B-4 Interior Finishes and Openings | $76,917 | 0.65% |
| B-5 Conveying Systems | $0 | 0.00% |
| B-6 Plumbing Systems | $0 | 0.00% |
| B-7 Fire Protection Systems | $0 | 0.00% |
| B-8 HVAC Systems | $9,272,037 | 78.03% |
| B-9 Electrical Systems | $1,080,032 | 9.09% |
| C-1 Site Work | $560,483 | 4.72% |
| C-2 Tunnels and Bridges | $0 | 0.00% |
| C-3 Landscape Structures | $0 | 0.00% |
| C-4 Utilities | $0 | 0.00% |
| Total | $11,883,378 | 1.00 |

condition (C-rating), which means approximately 65 percent or more of building components are in use and meet the services needs and construction standards. Moderate deterioration is presented in C rated buildings. In 5 to 10 years these C-rated buildings will become D rated or lower if proper maintenance is not performed. This figure also shows that 22% and 4% of public buildings of the State of Iowa are D rated and F rated, respectively. In all, more than one-quarter of Iowa's vertical infrastructure are failing or close to failing.

VIIAD assists facility managers in accomplishing more than fixing the above three problems. At the facility management planning and control level, VIIAD can help with cost management, time management, work management, risk management, property management, maintenance/operation management and services. For example, VIIAD can monitor or track deficiency items, manage facility space, and suggest preventive maintenance or repair plans.

# CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

## Summary

The purpose of the project of Vertical Infrastructure Inventory Assessment is to develop a tool to help the Department of General Services of Iowa to manage its facilities efficiently and effectively. Effective maintenance management requires knowledge of the inventory and physical condition of the buildings, the performance of building components over time, and the impact of component performance on overall building performance. A condition index rating system is necessary to provide a standard basis for rating current buildings and component conditions. Unfortunately, the Department of General Services of Iowa has neither a structured objective index rating system for buildings nor a procedure for capably monitoring the effectiveness of applied maintenance and repair.

Information needs were studied at three levels: component, building, and the owner. It was concluded that, in addition to needing component and facility condition data, a facility manager needs accurate, up-to-date, and accessible information on facility and component inventories in order to manage an M&R program efficiently and effectively. In traditional facility management system, even if this information exists, it was not easily accessible or transferable to any kind of database or facilities management system. Therefore, technology that can rapidly capture condition and inventory data, and efficiently transfer these data to a database, would be the best solution. Several available technologies were reviewed. One of the approaches for condition assessment, the condition index method, was adopted which satisfies several needs in both the inventory and inspection process.

The kind of information stored and managed in this system deals with facility types, uses, areas, materials, components, condition ratings, remaining years, deficiency quantities, and a variety of other related inventory data. In addition, digital imaging technology has been used to include both numerical data and visual images. Numerical data contains inventory information. Visual images provide more objective condition information, allowing operations staff to actually "see" the components or subcomponents when they are going to make a maintenance decision.

Based on the above results in Chapter 4, VIIAD was developed as a decision support tool for managing building assets, including inventory, inspection, condition assessment, and replacement budget management features in a Windows™ software environment. To support this effort, project researchers of Vertical Infrastructure Inventory and Assessment have developed condition indexes for assessing building condition, thus making the task of inspection and condition assessment uniform and rapid.

The VIIAD provides facility managers with a tool for performing effective, meaningful maintenance management. By combining engineering, architectural, and management methods and database management technology, the VIIAD is able to facilitate decision support so optimal building maintenance can be planned and accomplished at the lowest cost. The VIIAD also includes the methods for gathering, storing, manipulating, retrieving, and reporting information on building inspection and assessment.

## Conclusions

The development of a computer-aided facilities management system as described in this thesis demonstrates that the VIMS and its technologies can support complex processes. There are three advantages of VIMS/VIIAD, which are centered around the concepts of ownership, availability, and timeliness of information together with the notions of process implementation and control.

In the VIMS, the ownership of the information shifts from the individual to the corporation. In the traditional facilities management systems, for example, each individual knows only a small piece of information about the process. If any individual is removed from the process or data are lost, the knowledge is lost. In VIIAD, all the information resides in a central repository. The process is independent of the people who implement it.

The availability of the information in the VIIAD changes from reduced to fully available. The VIIAD is available 24 hours a days, 365 days a year. Timeliness of information changes from delayed to immediate. Additionally, the VIIAD can generate as many customized reports as needed. Reports are not delayed because all the information resides in a single database. The traditional system, on the other hand, requires clerical workers to locate, retrieve, process, and edit the information to generate reports.

Process implementation and control is also different in the VIIAD from the traditional facility management approaches. The characteristics mentioned above clearly demonstrate that the manager of the VIIAD has immediate access to information, and decisions are made based on experience, knowledge, and information. The more informed a facility manager is, the greater the chances for accurate cost estimation.

## Recommendations

Both the VIMS and VIIAD are subjected to further research. There are four major recommendations discussed as follows.

**Recommendation One.** The VIMS needs to include more value functions. Starting with the condition assessment methodology itself and continuing with budgeting estimating techniques, this system can include studies about the benefits and problems of the different assessment methods and alternative cost modeling techniques. For example, besides using life-cycle cost model, "Incremental Budget Model", "Coast Guard Methodology", "Air Force PRV-Facilities Investment Metric (FIM)", "Stanford Model", "Uniform Building Components Format Model", "Maintenance Resource Prediction Model (MRPM) System, and Army Installation Status Model" are all useful cost estimation model which will assist facility manager to making budget plans from different prospective. In addition, the suggested maintenance and repair plan can also be included in the VIMS and VIIAD to precisely satisfy the facilities maintenance requirements of the DGS.

Recommendation Two. Beside facilities inspection, the inventory data can also be obtained from other resources. Much of the project information created during design and construction can be used later useful for facilities management activities. Therefore, facilities information can be captured in computer formats during design and construction so that various facility management applications can use, share, and exchange the project information in an interoperable manner.

**Recommendation Three**. The accessibility of the information should be expanded from isolated to universal. Currently only the people with access to the particular office where the VIIAD resides can benefit from this information. VIIAD is still following a classic hierarchical approach of data distribution; only individuals who possess or “own” needed information add value to system. In contrast, if VIIAD can be further enhanced by Internet technology, it will not only support worldwide accessibility but also offer flexibility of physical location and real time updates.

In the future, the VIIAD can be developed using client-server architecture. Figure 5.1 presents a possible structure of a client-server system. The server system was developed on a PC running windows 9x or 2000. However, other platforms such as UNIX and Windows NT can be employed as well. The server application contains Internet browser, CGI Scripts, C++ applications, and the relational database (Microsoft Access). The server processes requests from clients by manipulating the database in order to produce HTML pages and / or customized CAD drawings. These CAD drawings will include hyperlinks (URLs) that represent the locations of building items; by followings a link, the user goes to the item’s homepage. An item’s homepage should include a collection of all the information related to the item: description, material, age, subdivisions, priority, status, pictures, comments, etc. The item’s homepage will also allow the user to review historical information by selecting the different years.

The client system consists of Internet Browser and software like AutoDesk WHIP! Plug-in running on a Windows 9x PC, WHIP! is a Web Browser Plug-in for viewing and navigating 2D vector graphics. This software will offer significant performance benefits over other Web file formats such as GIF and JPEG. For example, it will provide search, filter, pan, zoom, and embedded URL capabilities offering great maneuverability through complex, detailed drawings.

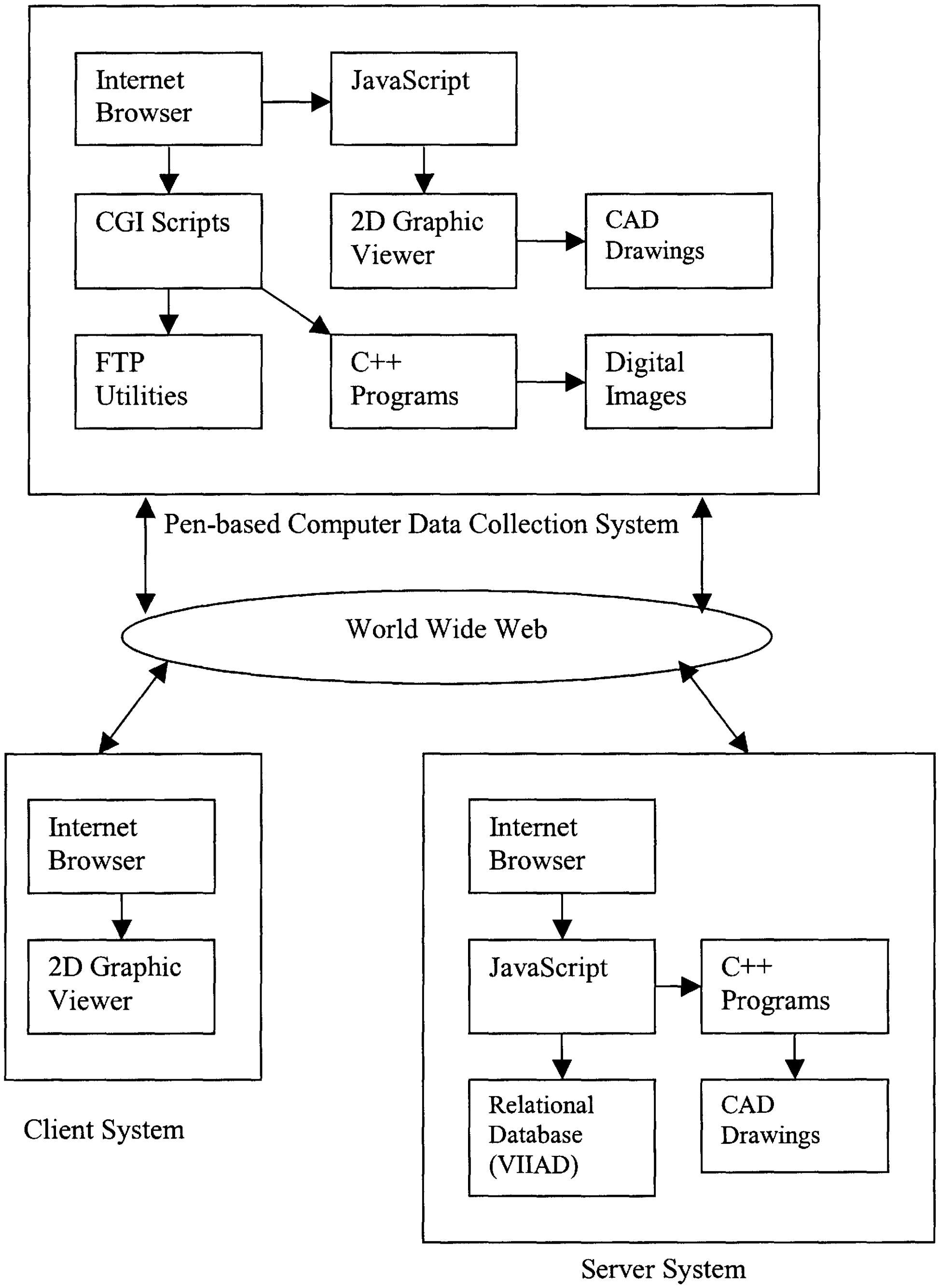



Figure 5.1 Future VIIAD Architecture

**Recommendation Four**. Manual techniques are currently the most commonly used practice, but they are considered subjective and inconsistent. Therefore, it is desirable to use automated techniques in the process of inspection in the future. For example, various sensors (such as ultrasound or infrared), which are becoming more and more popular in evaluating infrastructure conditions, can be applied to monitor non-visual deficiencies. Moreover, modern data input technology should also be integrated into VIIAD. A pen-based computer is a candidate for a data input device. The pen-based computer is a miniature computer with an ergonomic hardware interface, which can synthesize some of the features of personal digital assistants, personal communicators, notebooks, and desktops into one package. With a pen-based computer and a wireless remote transferring technology, data can be directly entered into the database instead of being written on a paper checklist first and then entered by some clerical workers. Base on above recommendation of expand VIIAD to Internet, the pen-based computer system should use a high-end computer with an Intel microprocessor, a hard disk, a color screen, a sound card, and a modem. The application that collects the data on the pen-based computer is built over Internet Browser. It is made up by a collection of HTML documents that also include Java Applets, JavaScript, and CGI Scripts. The pen-based computer system also included a digital camera that is connected to the serial port of the computer.

# APPENDIX A

# SAMPLE VERTICAL INFRASTRUCTURE INSPECTION CHECKLIST—STATE OF IOWA 1999

## 1999 INVENTORY & CONDITION ASSESSMENT - STATE OF IOWA

### B.4 Interior Finishes and Openings

Date: __________
Reviewed by: __________
Agency: __________
City: __________

Building: __________
Floor: __________
Room No. __________

*Orientation Sketch:*

**General Remarks:**

---

### B.4.1 Flooring

**Photo Key:** __________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

*Material:*

- ☐ Carpet
- ☐ Carpet Tile
- ☐ Asphalt/Vinyl Tile
- ☐ Sheet Flooring
- ☐ Masonry
- ☐ Wood
- ☐ Terrazzo
- ☐ Raised
- ☐ Ceramic/Quarry Tile
- ☐ Concrete
- ☐ Other: __________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.1.1 | Wear | |
| B.4.1.2 | Stains/Discoloration | |
| B.4.1.3 | Holes/Tears/Loose Seams | |
| B.4.1.4 | Loose or Broken Tiles | |
| B.4.1.5 | Shrinkage | |
| B.4.1.6 | Lifting/Cupping/Warpage | |
| B.4.1.7 | Cracks | |
| B.4.1.8 | Deteriorating Finish | |
| B.4.1.9 | Lacking Maintenance | |
| B.4.1.10 | Other (see Remarks) | |

**Remarks:** __________

### B.4.2 Base

**Photo Key:** __________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

*Material:*

- ☐ Wood
- ☐ Vinyl/Rubber
- ☐ Seamless
- ☐ Ceramic/Quarry Tile
- ☐ Other __________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.2.1 | Wear | |
| B.4.2.2 | Stains/Discoloration | |
| B.4.2.3 | Holes/Tears/Loose Seams | |
| B.4.2.4 | Loose or Broken Tiles | |
| B.4.2.5 | Shrinkage | |
| B.4.2.6 | Lifting/Cupping/Warpage | |
| B.4.2.7 | Cracks | |
| B.4.2.8 | Deteriorating Finish | |
| B.4.2.9 | Lacking Maintenance | |
| B.4.2.9 | Other (see Remarks) | |

**Remarks:** __________

*A = Excellent*
*B = Good*
*C = Adequate*
*D = Near Failing*
*F = Failed*
*X = Code Violation*

Agency: ________ City: _________ Building: ___________ Floor:___________Room:__________

**B.4.3** **Interior Walls** **Photo Key:** ___________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

***Material:***

- ☐ Wood
- ☐ Masonry
- ☐ Plaster
- ☐ Gypsum Board
- ☐ Ceramic Tile
- ☐ Stone
- ☐ Concrete
- ☐ Glass
- ☐ Metal
- ☐ Other ________________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.3.1 | Stains/Discoloration | ________ |
| B.4.3.2 | Cracks/Open Joints | ________ |
| B.4.3.3 | Moisture Damage | ________ |
| B.4.3.4 | Impact Damage | ________ |
| B.4.3.5 | Lacking Maintenance | ________ |
| B.4.3.6 | Other (see Remarks) | ________ |

Remarks: ____________________________________________

**B.4.4** **Finishes & Wall Coverings** **Photo Key:** ___________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

***Material:***

- ☐ Paint
- ☐ Stain
- ☐ Natural
- ☐ Clear Seal
- ☐ Vinyl/Fabric Wallcovering
- ☐ Wallpaper
- ☐ Acoustical Panels
- ☐ Other ________________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.4.1 | Stains/Discoloration | ________ |
| B.4.4.2 | Peeling/Flaking | ________ |
| B.4.4.3 | Rips/Tears | ________ |
| B.4.4.4 | Loose Material | ________ |
| B.4.4.5 | Moisture Damage | ________ |
| B.4.4.6 | Missing Elements | ________ |
| B.4.4.7 | Lacking Maintenance | ________ |
| B.4.4.8 | Other (see Remarks) | ________ |

Remarks: ____________________________________________

**B.4.5** **Ceilings** **Photo Key:** ___________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

***Material:***

- ☐ Acoustical Tile
- ☐ Plaster
- ☐ Gypsum Board
- ☐ Wood
- ☐ Metal Panel
- ☐ Exposed Structure
- ☐ Metal Grid
- ☐ Paint
- ☐ Stain
- ☐ Other ________________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.5.1 | Stains/Discoloration | ________ |
| B.4.5.2 | Peeling/Flaking | ________ |
| B.4.5.3 | Settlement/Sagging | ________ |
| B.4.5.4 | Broken/Missing Units | ________ |
| B.4.5.5 | Moisture Damage | ________ |
| B.4.5.6 | Cracks | ________ |
| B.4.5.7 | Damaged grid | ________ |
| B.4.5.8 | Lacking Maintenance | ________ |
| B.4.5.9 | Other (see Remarks) | ________ |

Remarks: ____________________________________________

*A = Excellent*    *D = Near Failing*
*B = Good*    *F = Failed*
*C = Adequate*    *X = Code Violation*

Agency: ________ City: _________ Building: ___________ Floor:___________Room:__________

**B.4.6** **Interior Doors, Frames, Hardware & Windows** **Photo Key:** ____________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

*Material:*

- ☐ Wood Door
- ☐ Wood Frame
- ☐ Steel Door
- ☐ Steel Frame
- ☐ Aluminum/Glass Door
- ☐ Aluminum Frame
- ☐ Paint
- ☐ Stain
- ☐ Laminate
- ☐ Other ____________________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.6.1 | Deteriorated Finish | ____________ |
| B.4.6.2 | Loose Veneer | ____________ |
| B.4.6.3 | Rust | ____________ |
| B.4.6.4 | Missing Hardware | ____________ |
| B.4.6.5 | Malfunctioning Hardware | ____________ |
| B.4.6.6 | Glass Broken | ____________ |
| B.4.6.7 | Lacking Maintenance | ____________ |
| B.4.6.8 | Other (see Remarks) | ____________ |

Remarks: ____________________________________________________________

**B.4.7** **Casework** **Photo Key:** ____________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

*Material:*

- ☐ Wood
- ☐ Laminate
- ☐ Metal
- ☐ Paint
- ☐ Stain
- ☐
- ☐ Other ____________________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.7.1 | Deteriorated Finish | ____________ |
| B.4.7.2 | Missing Components | ____________ |
| B.4.7.3 | Malfunctioning Hardware | ____________ |
| B.4.7.4 | Improper Anchorage | ____________ |
| B.4.7.5 | Damaged Top | ____________ |
| B.4.7.6 | Lacking Maintenance | ____________ |
| B.4.7.7 | Other (see Remarks) | ____________ |

Remarks: ____________________________________________________________

**B.4.8** **Specialty Items** **Photo Key:** ____________

*Condition Rating:*

| A | B | C | D | F | X |
|---|---|---|---|---|---|

*Estimated Remaining Life in Years:*

| Indef | 20 | 15 | 10 | 5 | 3 | 2 | 1 | Unk |
|---|---|---|---|---|---|---|---|---|

*Material:*

- ☐ Toilet Partitions
- ☐ Toilet Accessories
- ☐ Movable Wall
- ☐ Chalk/Tack/White Boards
- ☐
- ☐ Other ____________________

| *Deficiency:* | | *Est. Quantity:* |
|---|---|---|
| B.4.8.1 | Deteriorated Finish | ____________ |
| B.4.8.2 | Missing Components | ____________ |
| B.4.8.3 | Malfunctioning Hardware | ____________ |
| B.4.8.4 | Improper Anchorage | ____________ |
| B.4.8.5 | Lacking Maintenance | ____________ |
| B.4.8.6 | Other (see Remarks) | ____________ |

Remarks: ____________________________________________________________

*A = Excellent* *D = Near Failing*
*B = Good* *F = Failed*
*C = Adequate* *X = Code Violation*

# APPENDIX B

# DISCUSSION OF TERMS USED IN TABLE 2.1

# DISCUSSION OF TERMS USED IN TABLE 2.1 (p.26)

1. **Decision Type:**

**Inspection programming and resource allocation**—involves decisions about the type and frequency of inspections to be performed on a facility or building, the amount of money to be allocated for inspections, and the staffing required. Equipment budgets and allocations for inspections are decided at Level I. In addition, buildings to be inspected are identified and building inspection priorities are established.

**Maintenance Decisions**—involves decisions on the structure and allocation of the maintenance budget. Buildings that must be repaired or replaced to ensure safety and code compliance are also identified. In addition, buildings or components that should be replaced because their maintenance costs exceed replacement cost or they no longer function effectively are identified. Areas where maintenance expenditures can be reduced by increased preventive maintenance or by improving inspections are established. The results of these decisions are prioritized to ensure maximum efficiency.

**Maintenance Budget**—refers to establishing the total budget required to maintain the facility at a specified performance standard. Ideally, the budget is based on the actual condition of the entire facilities inventory and the facilities' requirements.

**Inspection Technology**—defines the methodology, frequency, costs, and technology required to assess the condition of a building. An example is a water distribution system. It requires an inspection methodology that begins with meter surveys and break history analysis, and progresses in detail to noise correlation and local geophone measurement.

**Maintenance Specification**—defines the work required to bring the building up to an acceptable operating standard and maintain it at that standard.

**Repair/Replace/No Action Decision**—is it more cost-effective to repair a defective facility, replace it, or defer action to some later time?

**Frequency, Extent, and Technology of Inspection**—decide when a building component requires inspection in order to maintain it prescribed level of operation. Is this decision based on a time interval or a performance standard? Decide what level of inspection information is required for a particular component and what level of dollar investment this will require. Determine what physical information about the component will be needed to provide this condition information. Identify equipment and instrumentation needed to provide this information.

**2. Information Requirements:**

**Inventory Data**—a complete record of all vertical infrastructures defined by DGS in terms of function, size, and composition. This includes using the orientation sketches of the building that illustrate the spatial relationships between buildings, sizes, identifications, and uses.

**Cost of Maintenance**—needed to establish budgets and prioritize work when funding is constrained.

**Inventory and Inspection of Facilities to Determine Condition**—a complete inventory and record of the condition of all facilities is needed. An inventory that identifies types and number of components within a building must also be maintained. An objective condition and performance rating for each building must be maintained based on the actual physical condition of its components parts.

**Condition/Performance Assessment**—evaluation of the actual condition and performance of facilities (individual and by facility type).

**3. Approach:**

**Automation to Aid in Data Acquisition**—refers to automating the procedure of converting raw inventory and inspection data into a form useful for integration into a facilities management system. It also includes the digital imaging techniques to enable the rapid, accurate acquisition of large amounts of visual data for storage in the database. Labor-intensive inventory initialization requirements at Level II, inspectors site visit to each facility can be reduced through digital imaging.

**Database Management**—refers to the maintenance and use of actual facility inspection data for all the facilities. Three key concepts are involved: (1) the initialization and maintenance of a facility inventory; (2) the association of condition and performance data into this inventory; and (3) the ability to manipulate, sort, and interpret the data in meaningful ways.

**Resource Allocation**—prioritization of maintenance resource usage based on the knowledge of required performance levels for facilities.

**Optimize Life-Cycle Cost**—maintaining facility performance at a prescribed level while minimizing the cost of operation and maintenance.

**Data Access and Database Management**—the database viewed from the building level is composed of both building and component inventory. The building is viewed both as a unique entity and as the sum of its components. This latter view requires each component to be inventoried and its condition assessed. Buildings are also grouped by agency type.

**Decision Models and Life-Cycle Cost Analysis**—such models, addressing maintenance strategies, should incorporate projected expense over the life cycle of the facility or components.

**Inspection, Condition Rating And Data Interpretation**—For Level III, large amounts of detailed information about individual components must be entered into the database, so the information can then be assembled, interpreted, and related to other decision levels. The interpretation of inspection data results in a diagnosis of component condition.

**4. Technology:**

**Database Management System (DBMS)**—refers to computer software that structures a database of maintenance information to be used to improve facility maintenance management and decision-making. The Microsoft Access is an example of a microcomputer package. All information in the database is "keyed" to a building number from which it can be referenced.

**Expert Systems**—computer software providing automated decision support, assisting in the identification and prioritization of maintenance needs. An example would be a software package with the following inputs and outputs. Assume input requirements of the DGS's facility inventory, maintenance budget, and a condition rating for each facility. A possible output would be the identification of facilities for which the most cost-effective option over the next year would be replacement rather than continuing maintenance.

However, expert systems related to inspection and maintenance management are in their infancy and are not well developed commercially.

**Nondestructive Evaluation Method**—refers to a class of methodologies developed in manufacturing, aerospace, and nuclear industries for detailed analysis of component condition.

# APPENDIX C

# SAMPLE REPORTS FROM VIIAD

# A-2 General Mechanical Data

| Condition Ratings | A= Excellent | C=Adequate | F=Non-Functional or Beyond Repair |
|---|---|---|---|
| | B=Good | D=Deteriorating | X=Possible Non-Compliance |

**Location** Anamosa **Agency** Corrections

**Building Name** **Asp North House #2** Condition Assesded 1999

| Bldg # | Mech. Sys. | Gas | Water | Control Type | Heating Source | Heating Capacity(mbh) | Cooling Source | Cooling Cap.(Tons) | Water Service Size | Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| 1083 | Used | People Gas | Wells Off Site | Pneum | Central Plant | N/A | Air-Cooled | | 4" Service | **C** |

**A-2General Remarks**

**Building Name** **Auto Body/Voc. Welding #16** Condition Assesded 1999

| Bldg # | Mech. Sys. | Gas | Water | Control Type | Heating Source | Heating Capacity(mbh) | Cooling Source | Cooling Cap.(Tons) | Water Service Size | Rating |
|---|---|---|---|---|---|---|---|---|---|---|
| 1123 | Used | Peoples Gas | 3-Wells Off-Site | Pneum | Central Plant | N/A | None | N/A | N/A | **D** |

**A-2General Remarks** This building ic currently being used. However, it is scheduled for demolition.

**Building Name** **Cheese Factory #27A** Condition Assesded 1999

| Bldg # | Mech. Sys. | Gas | Water | Control Type | Heating Source | Heating Capacity(mbh) | Cooling Source | Cooling Cap.(Tons) | Water Service Size | Rating |
|---|---|---|---|---|---|---|---|---|---|---|

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# A-1 General Architectural Data

| Condition Ratings | | | |
|---|---|---|---|
| | A= Excellent | C=Adequate | F=Non-Functional or Beyond Repair |
| | B=Good | D=Deteriorating | X=Possible Non-Compliance |

**Location** Anamosa **Agency** Corrections

| **Building Name** | **Agriculture Building 1 #36E** | | | | | Condition Assesded 1999 | |
|---|---|---|---|---|---|---|---|
| Bldg # | Original Use | Current Use | # of Floors | Area(SF) | Const. Date | Replace Value | Rating |
| 1158 | AGRICULTURE | AGRICULTURE | 1 | 250 | UNKNOWN | TBD | **D** |

**General Remarks**

| **Building Name** | **Agriculture Building 2 #36F** | | | | | Condition Assesded 1999 | |
|---|---|---|---|---|---|---|---|
| Bldg # | Original Use | Current Use | # of Floors | Area(SF) | Const. Date | Replace Value | Rating |
| 1159 | AGRICULTURE | AGRICULTURE | 1 | 150 | UNKNOWN | TBD | **C** |

**General Remarks**

# A-3 General Electrical Data

| **Condition Ratings** | A= Excellent | C=Adequate | F=Non-Functional or Beyond Repair |
|---|---|---|---|
| | B=Good | D=Deteriorating | X=Possible Non-Compliance |

**Location** Anamosa **Agency** Corrections

| **Building Name** | **Asp North House #2** | | | | Condition Assesded 1999 | |
|---|---|---|---|---|---|---|
| Bldg # | Electrical Sys. | Utility Com. | Primary Elec Characters | Secondary Elec Characters | Service Size (amps) | Rating |
| 1083 | Used | Alliant Utilities | 2400V-3 diameter-3W | 120/208V-3 diameter-4W | 1200 | **C** |

**A-3General Remarks** served through infirmary switchboard from substation #8

| **Building Name** | **Auto Body/Voc. Welding #16** | | | | Condition Assesded 1999 | |
|---|---|---|---|---|---|---|
| Bldg # | Electrical Sys. | Utility Com. | Primary Elec Characters | Secondary Elec Characters | Service Size (amps) | Rating |
| 1123 | Used | Alliance Utilities | 2400V-3 diameter-4W | 120/208V-3 diameter-4W | 225 | **D** |

**A-3General Remarks** Building is scheduled for demo.

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| **Building Name** | **Barn (F6-C)** | | | | Condition Assesded 1999 | |
|---|---|---|---|---|---|---|
| Bldg # | Electrical Sys. | Utility Com. | Primary Elec Characters | Secondary Elec Characters | Service Size (amps) | Rating |
| 1101 | | Alliant Utilities | 1 diameter-2W overhead | | 0 | **D,X** |

**A-3General Remarks** non-accessible panel, unapproved exterior wiring methods, insulation is failing, No GFI on exterior receptacles

# A-4-1-1 HC Parking Remote From Entry

| Location | Agency | Building Name | Building Number | A-4 Location | A4-1 Location: |
|---|---|---|---|---|---|
| Cherokee MHI | Human Services | Boiler Building #15A | 1462 | All | East of building |
| Cherokee MHI | Human Services | Donohoe #29 | 1466 | All | East of bldg. |
| Cherokee MHI | Human Services | Laundry/Motor Pool #33 | 1468 | All | South & North of Bldg. |
| Cherokee MHI | Human Services | Maintenance #10 | 1460 | All | Northwest parking |
| Cherokee MHI | Human Services | Power #15 | 1461 | All | east of bldg |
| Cherokee MHI | Human Services | Store Building #9 | 1459 | All | |
| Cherokee MHI | Human Services | Volding #40 | 1470 | All | North of bldg |
| Cherokee MHI | Human Services | Wade #28 | 1465 | All | West of bldg |
| Cherokee MHI | Human Services | Wirth #30 | 1467 | All | North of bldg |
| Clarinda MHI | Human Services | Employee's Lodge #19 | 1309 | All | South of Lodge |
| Des Moines | Capitol Complex | Iowa State Capitol | 1001 | All | East |
| Des Moines | Cultural Affairs | New Historic Building | 1002 | All | Northeast of Building |
| Des Moines | Cultural Affairs | Terrace Hill | 1081 | All | West Entrance |
| Des Moines (Johnston, 6450 Corpora | Cultural Affairs | Iowa Public Television | 1990 | All | North Side |
| Eldora | Human Services | Living unit 7&8 #17 | 1353 | All | Bldg #17 |
| Fort Dodge Correctional Facility | Corrections | Close Housing(Bldg. B) | 2061 | All | Not Provided |
| Fort Dodge Correctional Facility | Corrections | Industries (Bldg. I) | 2068 | All | Parking Lot |

# A-5-2-1 Insufficient Number of Exits

| Location | Agency | Building Name | Bldg # | A5-1Type of Use | Floor # |
|---|---|---|---|---|---|
| Clermont | Cultural Affairs | Museum | 1808 | Museum/Other Assembly/Pu | Second |
| Clermont | Cultural Affairs | Union Sunday School | 1807 | Museum/Other Assembly/Pu | 1 |
| Fort Madison - Iowa State P | Corrections | Library+ Storage | 1612 | Museum/Other Assembly/Pu | 1 |
| Fort Madison - Iowa State P | Corrections | Laundry | 1584 | Utility, LAUNDRY | 1 |
| Cherokee State Patrol | Public Safety | Highway Patrol Post #1 | 1785 | Office | Basement |
| Mason City State Patrol | Public Safety | Highway Patrol Post #1 | 1798 | Office | Basement |
| Des Moines State Patrol (59 | Public Safety | Iowa State Patrol Supply | 1805 | Storage | Main Floor |
| Des Moines State Patrol (59 | Public Safety | Iowa State Patrol Supply | 1805 | Storage | 2nd. Floor (1953 Bldg) |
| Woodward State Hospital/Sc | Human Services | Birches #16 | 1851 | Office Storage | First |
| Woodward State Hospital/Sc | Human Services | Birches #16 | 1851 | Office Storage | Second |
| Woodward State Hospital/Sc | Human Services | Birches #16 | 1851 | Office Storage | Third |
| Woodward State Hospital/Sc | Human Services | Supply Depot #21 | 1859 | Storage | Upper |
| Woodward State Hospital/Sc | Human Services | Power House (New) #17 | 1852 | Utility | 1 |
| Anamosa | Corrections | Kitchen/Dining Hall #3 | 1084 | Other | kitchen/dining |
| Anamosa | Corrections | Kitchen/Dining Hall #3 | 1084 | Other | auditorium-2 |
| Des Moines | Capitol Complex | Wallace | 1000 | Office | 1 |
| Des Moines | Capitol Complex | Iowa State Capitol | 1001 | Office | 0 |

# Alphabetical List of Buildings by Location

*Total Area (s.f.)* **10,270,598**

| Location | Building Name | Building Number | Gross Area(s.f.) |
|---|---|---|---|
| Anamosa | | | |
| | | *Total area by location(s.f.)* | **542,457** |
| | **Agriculture Building 1 #36E** | *1158* | 250 |
| | **Agriculture Building 2 #36F** | *1159* | 150 |
| | **Asp North House #2** | *1083* | 33,450 |
| | **Auto Body/Voc. Welding #16** | *1123* | 13,200 |
| | **Barn (F3-B)** | *1095* | 6,400 |
| | **Barn (F6-C)** | *1101* | 5,560 |
| | **Barn Granary (F1-D)** | *1109* | 12,000 |
| | **Bunk house (F6-E)** | *1103* | 1,840 |
| | **Cattle Shed (F3-C)** | *1096* | 2,125 |
| | **Cheese Factory #27A** | *1141* | 5,500 |
| | **Commissary #20** | *1127* | 2,500 |
| | **Compost #25D** | *1135* | 2,100 |

# Classified by Agency

**Agency** Capitol Complex

**Number. of Bldgs:** 14 **Gross Area by Agency(sq.ft.):** 1,572,403

**Location** Des Moines

| Building Number | Building Name | Gross Area(sq.ft.) |
|---|---|---|
| 1000 | Wallace | 228,400 |
| 1001 | Iowa State Capitol | 330,950 |
| 1010 | Grimes State Office Bldg. | 107,600 |
| 1078 | Lucas | 223,720 |
| 1079 | Hoover | 276,250 |
| 1171 | Central Energy | 7,855 |
| 1172 | Maintenance Building | 26,400 |
| 1230 | Capitol Complex Tunnels | 0 |
| 1550 | Vocational Rehab - Jessie Parker Buildi | 129,418 |

**Location** Des Moines 1000 E Grand

| Building Number | Building Name | Gross Area(sq.ft.) |
|---|---|---|
| 1026 | Workforce Development | 110,800 |

**Location** Des Moines 150 Des Moines St

| Building Number | Building Name | Gross Area(sq.ft.) |
|---|---|---|
| 1992 | Workforce Development II | 18,972 |

**Location** Des Moines 213 E 7th St

| Building Number | Building Name | Gross Area(sq.ft.) |
|---|---|---|
| 1548 | Records & Property Center | 68,400 |

**Location** Des Moines 215 E 7th St

| Building Number | Building Name | Gross Area(sq.ft.) |
|---|---|---|
| 1170 | Central Micrographics | 9,438 |

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