THE USE OF GEOGRAPHICAL INFORMATION SYSTEMS FOR AIRPORT ENGINEERING AND MANAGEMENT

Michael Thomas McNerney

Research Report Number ARC-700

Prepared in cooperation with the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

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ABSTRACT

The use of geographical information systems (GIS) for transportation has been dominated by the highway transportation sector. The author proposes that airports develop a multi-user GIS for multiple applications to maximize use while minimizing development costs. In late 1993, the author surveyed 172 of the nation's busiest certificated airports concerning their present and planned use of GIS. With a 48 percent response rate to the survey, 58 percent of the airports indicated that they actually use or plan to use a GIS within 36 months. The survey listed 18 potential applications of GIS for airports that can be grouped into infrastructure management, environmental analysis and management, and basic GIS information management functions. Detailed explanations for the potential application of GIS for pavement management; infrastructure management; noise analysis, mitigation, and management; storm water management; and project management are presented. A small GIS to demonstrate the feasibility of using GIS for pavement management, noise analysis, and storm water pollution prevention plans is developed and described. Suggested specifications for airports to consider when developing a GIS are also developed for several applications. The author concludes that GIS will rapidly gain in use at our nation's airports; that airports will begin developing multiple GIS applications; and that the most development will occur at busier airports.

Acknowledgments

The author wishes to express thanks to Steven B. Cornell, PE and Joseph F. Zumwald of Woolpert for their assistance in the final review and publication of this report. Their assistance will make this report more widely available to airports and GIS professionals.

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TABLE OF CONTENTS

CHAPTER 1. AIRPORT GIS

Today our national aviation system is faced with ever increasing constraints on airport capacity and increasing costs to the users in airport delays. Growth in passenger traffic is expected to double within ten years and construction of new airports is very limited. Only two new airports (Dallas/Fort Worth International and Southwest Regional) have been constructed in the last 22 years and only two airports (Denver International and Austin Bergstrom International) are currently under construction.

The financial burdens on the US airline industry in the current climate of deregulation are well documented. In 1993, nearly every US airline lost money. The federally funded airport improvement program (AIP) for airport construction has decreased for the last two years although the funds paid into the aviation trust fund have not. Airlines are making schedule and hubbing decisions based upon demand, market shares and cost per enplaned passenger at the airport. Consequently, airports are competing among each other to provide better service at lower cost to the airlines and hence the traveling public.

One way of improving efficiency at airports is better engineering, management, and decision making by better management of information and data. The development of a multiple user, multiple application geographic information system can be one method of reducing costs and improving efficiency at airports with scheduled airline traffic.

RESEARCH OBJECTIVE

The objective of this research effort was to prove the premise that airport authorities should develop multiple user, multiple application, geographic information systems for airport managers and staff to use as a significant tool for airport engineering and management. The author offers as proof of this premise the following items of discussion:

1. The conduct and analysis of a survey of the current and planned use of GIS at US airports documenting the interest and needs of the airports.
2. A detailed description of several potential engineering and management applications where GIS can serve as a highly effective tool for managers and staff.
3. The development of sample specifications for airports to consider in the development and implementation of an airport GIS for several popular applications.
4. The development and documentation of a small demonstration GIS that can be used to graphically demonstrate the potential for using some engineering and management applications at an airport.

SCOPE OF REPORT

The scope of this report was limited by the fact that sponsorship was not obtained for this research. There is very little opportunity for graduate students in transportation engineering to receive sponsorships in airport engineering, especially in comparison to the amount of research funding available in other modes of transportation. There is great interest in airport engineering by the graduate students and The University of Texas at Austin is attempting to start a nationally recognized airport engineering research program.

The lack of sponsorship precluded the full development of a single application such as pavement management or noise analysis. This research was limited to discussing how several applications could be developed and implemented at airports using GIS and by developing specifications that airports can use for developing specific applications. The results of this research can be used by airports interested in better management and engineering to better define what a GIS should do before hiring a consultant to develop the airport GIS.

WHAT CAN GIS DO FOR AIRPORTS?

Why do airport authorities want a GIS? The personality of each authority that manages an airport is as different as the surrounding communities and governing bodies. The reasons that airports desire a GIS are also varied. The impetus for development of a GIS may come from an individual engineer or planner, it may come about from difficulty in understanding a specific problem, it may come from the surrounding communities or from the municipal government, it may come from an opportunity for an application which presents itself, and it may even result from a conscious management decision.

Management of airports is a very dynamic and very exciting profession. If one looks at the changes that have occurred in aviation and airports in the last 20 years, what is constant is that change is always occurring. New aircraft, new regulations, new technology, new procedures, and new construction are all part of the job. Computer management tools are often highly effective for managing anything that is always in a state of change. GIS is one such computer management tool that has great potential for the management of an airport. Although GIS is an excellent management tool, it is also an excellent analysis tool for engineers and planners. Moreover, this tool is an information system; it could even become the airport information system. A GIS can be as small or as large and all-encompassing as is desired.

The reasons that a GIS is needed and wanted at airports vary greatly, and the following chapters will give some specific applications. Some of these applications are a result of the management capabilities of a GIS: pavement management, infrastructure management, management of lease space, management of noise mitigation programs or management of projects. Some of the applications are a result of the analytical capabilities of a GIS: noise analysis, noise monitoring, and pavement analysis. One of the reasons that airports need GIS is to integrate data from several sources and display it.

PROPOSED AIRPORT GIS

The author proposes that airport authorities develop geographical information systems at their airports with the intention of permitting multiple users and multiple applications. Many of the GISs now being developed are being designed for a single application. In the case of Dallas-Fort Worth Airport, three independent GISs were intended to be developed for three applications described in subsequent chapters.

Funding is a major limitation at airports, as the FAA monitors and approves most major projects under development. Most of the potential applications of GIS at airports will qualify for federal funding either under the airport improvement program, planning grants or under the voluntary Part 150 program. The real key is to develop the GIS under the application that is eligible for funding and to add additional applications later as time and resources permit for cost-effectiveness.

The major cost of developing a GIS is not the hardware or software required. The major cost by far is the development of the graphic and attribute data. If a GIS is going to be developed for noise mitigation, most of the airfield pavements must be included in the graphic data representing the airfield anyway. If the graphic data representing the airfield are included in such a way that a pavement management system can be supported with the same GIS using a different attribute database, the cost of developing the application has been reduced considerably.

If an airport is large enough to invest in a management system of some kind, the airport is probably large enough to have a GIS. Even small airports have to prepare master plans, airport layout plans, and other federally mandated requirements such as a storm water pollution prevention plans. Since these requirements must be completed anyway, it will eventually save money if they can be computerized in CAD drawings. Once CAD drawings are completed, an entry-level GIS can be started on a personal computer.

By prior planning for future GIS applications, both in the airport's data management plan and in the development of a GIS application that is funded, future GIS applications can be added at reduced cost with a better chance for becoming cost-effective. The ultimate power and usefulness of a GIS is not measured by its ability to perform an intended single application; the real power comes when it can be used as a tool to quickly analyze a critical problem which was not even contemplated when the system was actually designed.

DEFINITIONS

What is a geographical information system (GIS)? An important first step in defining GIS is to define what is an information system. All complete information systems have four major functional components:

1. Data Collection
2. Data Management
3. Data Analysis
4. Data Visualization

Regardless of whether it is a geographic information system (GIS), an executive information system (EIS), or a management information system (MIS), the complete information system must be capable of performing the above four functions.

The United States Geological Survey (USGS) is the federal organization responsible for the publication of nearly all the non-military topographical maps in this country and a lead organization in the setting of standards for mapping and map-related products. The USGS defines GIS as "a computer hardware and software system designed to collect, manage, manipulate, analyze, and display spatially-referenced data."[1] This leads one to ask what is spatially-referenced data. The USGS defines spatially-referenced data as computer-readable, geographically referenced features that are described by both geographic position and attributes.

This report is about GIS for transportation, so what is a transportation definition of GIS? The Pennsylvania Department of Transportation, one of the state leaders in GIS technology, defines GIS as "an automated system designed to allow users to more easily filter, manage, analyze, display and share location-oriented data and associated explanatory information."

Each of the above definitions describes a system that performs the four functions of an information system. GIS is not just a data collection system or just a data analysis package, not just a database, or not just a system to graphically visualize data, but rather its a complete system that can perform each function. Another common requirement in the definitions is that GIS is both a computer hardware and a software system. Another common item in GIS definitions is that a GIS can integrate geographically oriented data (data with a location in space) with other related explanatory or attribute data which could for example reside in a relational database.

There is not one commonly agreed upon definition of what is a GIS and nearly every agency has their own definition. However, as a working definition for this dissertation, it is assumed that a GIS is a methodology involving a computerized data management system designed to capture, store, retrieve, analyze and display spatially-referenced data.

Figure 1.1 shows one commonly used method of describing a GIS in which there are several layers of geographically located data. The data layers contain information about the location and boundaries of facilities, infrastructure, and other natural or man-made features. The layers of data can be used for spatial analysis such as to determine which buildings and dwellings are located within a noise contour.

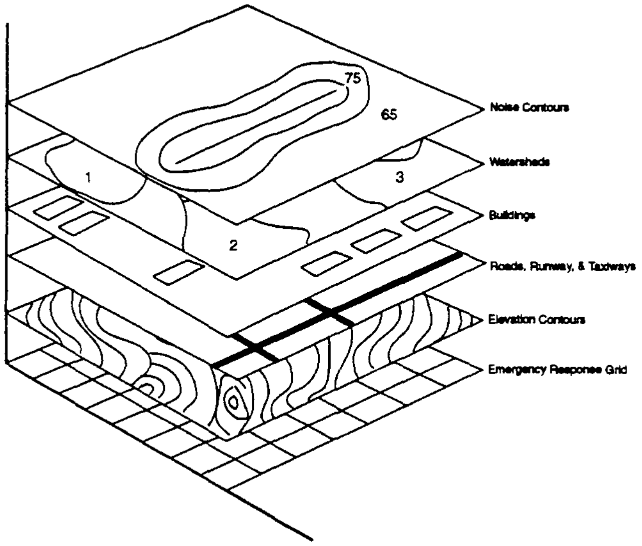

Figure 1.1 Example of Different Data Layers in an Airport GIS

There are many such layers or themes of data for airports. It is also important the data be accessible to many different users at the airport and be flexible to perform many different types of analyses including ones that have not yet been anticipated. Figure 1.2 shows examples of several different potential users of an airport GIS and potential applications the users might coordinate with each other.

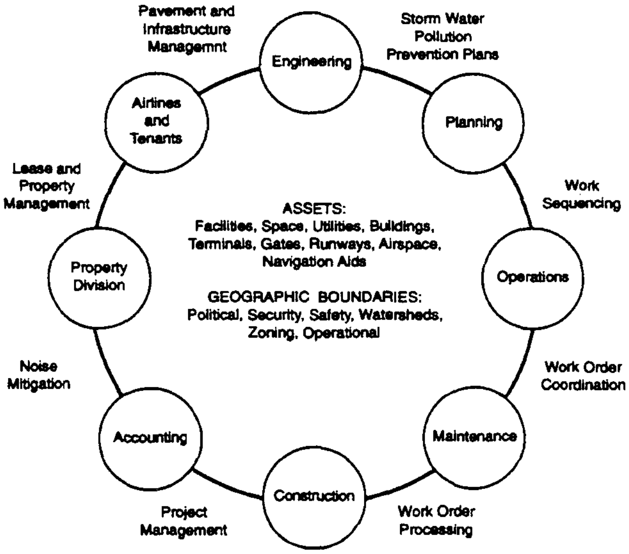

Figure 1.2 Examples of Multiple Application and Multiple Users of Airport GIS

DISTINCTION BETWEEN GIS AND OTHER INFORMATION SYSTEMS

The distinction between a GIS and other information systems is not that a GIS uses geographically referenced or spatial data. Other systems also use geographic information such as automated mapping (AM), computer cartography, and land information systems (LIS). There is an entire industry of professionals that caters to those specific applications. The real distinction between GIS and other systems is the ability of a GIS to perform spatial analysis.

Spatial analysis is the ability to analyze the spatial relationships of objects to each other. For example, to determine which homes in a specific district are within 500 feet of an overhead power line, requires knowing the locations both of the power lines and of the homes and performing the spatial analysis to determine if the 500 foot horizontal distance criterion is met. It is this spatial analysis capability of a GIS, coupled with the tremendous ability to integrate data and visually display it, that has caused the great popularity of GIS for a multitude of professions.

Often confused with GIS is computer-aided drafting or computer-aided design (CAD). There have been many improvements in the state-of-the-art of CAD in the last several years. With CAD packages now available on personal computers, it is possible to have geographically referenced drawings. It is also possible, with what has been termed as "SmartCAD," to attach information in a relational database to an object in a CAD drawing. This process is similar enough to be confused with GIS, especially since some GIS packages are using CAD programs for the editing of the graphic data. However, the distinction between a true GIS and SmartCAD is that only a GIS can perform spatial analysis using the graphic and attribute data.

Another reason for the confusion concerning what is a GIS is that some software vendors are representing their products as GIS when not all the capability of performing spatial analysis is actually there. Some products can do little more than graphically display data. Other products are severely limited in their spatial analysis capabilities. Another factor adding to the confusion is that some of the intrinsic capabilities or advantages of GIS can be achieved without the spatial analysis component. In the following chapters several potential applications of GIS will be presented, but not all the applications will require the spatial analysis capability of a GIS.

For example, some of the infrastructure management applications can be performed by specialty software programs designed for automated mapping or facility management (AM/FM). However, a GIS can perform the automated mapping function, but AM/FM software cannot perform the spatial analysis capabilities of a GIS. GIS is an engineering tool with capabilities that may not be immediately recognized as needed; but once the capabilities are recognized, new applications and analyses can be performed.

INTRINSIC GIS CAPABILITIES

Having defined what a GIS is and is not, the next step is to define some of intrinsic capabilities of a computerized GIS. One of the primary reasons that GISs are developed is to visually see the spatial relationship of data. An intrinsic capability of all GIS is the ability to graphically display and compare raw or queried data. The old adage is that a picture is worth a thousand words. Data becomes information only after a relationship can be visualized between the raw data and something else.

Data visualization is a major selling point for GIS because far more information can be conveyed much faster by graphically visualizing the relationships of either raw data or queried data. If someone were trying to justify a pavement rehabilitation project in a certain area, he/she would be better able to convince the decision makers with a graphical representation of the relative severity of distress levels of each geographically located pavement than by providing a multiple page, computer generated, tabular report.

Another capability that is viewed as a definite advantage is the ability of GIS to integrate multiple databases. An important point about GIS is that the attribute databases need not reside on the desktop where the analyses are performed. It is completely feasible to graphically display the results of a query on one remote database with the results of another query from a second database. This is an important aspect of GIS and is used frequently. One advantage this provides is that several users with access privileges can analyze data that belong to another system, but the individual doesn't have to duplicate the data or have the responsibility of keeping the other person's data up to date.

Another advantage, not normally considered when purchasing or developing a GIS, that is quickly realized after using GIS: it provides an effective mechanism for detecting errors in the database. If the graphic features are linked to the attribute database and queries are made, it is obvious if a section is missing or displays an unusual value. These errors are far more often present in large databases than one would think. Any large database with manually entered data is highly susceptible to errors.

During this research, while using several PennDOT databases with attribute data for segments of Interstate Highway 80 (which carries traffic across Pennsylvania), many such errors or missing data in the downloaded files were discovered using a pilot GIS to graphically display the data for the highway segments.[3] This method has been so effective and popular for finding database errors that it is becoming standard practice to validate data in this manner.

DISCUSSION OF THE LITERATURE

In the transportation literature, by far the most discussion of GIS concerns the highway sector. The principal applications for GIS for the highway sector have been for pavement management and infrastructure management, such as photo logging of sign inventory. The Federal Highway Administration (FHWA) has not taken the leadership role in GIS, but has initiated several noteworthy projects.

The first GIS that was developed for FHWA was GRIDS. This was a self-contained GIS which the FHWA developed and distributed free to states — but states could not change any data; they could only display what already had been prepared on the federal highway network. Even though this was called a GIS, it did not permit any spatial analysis.

Another notable GIS project undertaken by FHWA included sponsorship of education in the form of funding the development and teaching of GIS workshops. These workshops were lead by Simon Lewis of GIS/TRANS and David Fletcher, who was with Wisconsin DOT at that time. These workshops and the follow-on National Highway Institute course have helped spur interest among state highway departments in using GIS for infrastructure management and network analysis.

FHWA's most recent project has been the development of a GIS depicting the proposed National Highway System, including the Eisenhower Interstate Highway System, Congressional High Priority Routes, and the Strategic Highway Network routes in all 50 states. The proposed National Highway System GIS has been completed in an ARC/INFO GIS, but FHWA has not released the data for public use. The horizontal accuracy for road alignment is only in the neighborhood of 100 meters.

The Federal Aviation Administration has not initiated any major GIS-related research and development projects, with one exception. The US Air Force and the Army Corps of Engineers are developing CAD standards that may lead to standards for GIS mapping in the future. The Army Corps of Engineers uses the GRASS GIS system, because they developed it themselves and it is not a proprietary system. Recently, the FAA contracted with Wyle Laboratories to link the Integrated Noise Model Version 3 to the GRASS GIS for the evaluation of military low-level training routes.

In the area of state GIS initiatives for transportation, the most widely noted efforts were those of the Wisconsin DOT. As discussed in more detail in Chapter 3, Wisconsin DOT implemented a state-wide GIS during its implementation of a decision support system for pavement management.

The coordinated state efforts on GIS in transportation (GIS-T) have been primarily focused on two efforts. The first is recently completed research Project 20-27 funded by the National Cooperative Highway Research Program (NCHRP) which has resulted in the publication of on a report of the application of GIS for Transportation.[4] The report is an excellent report from the perspective of a state highway agency, but does not address the aviation sector of transportation. The report highly recommends that state DOTs revitalize a strategic planning process addressing GIS-T in conjunction with complementary computer technologies for satisfying the needs of the state DOTs.

The second major coordinated state effort in GIS-T is a follow-up on project to the NCHRP 20-27 with a multimodal emphasis that many states have contributed. This research effort began in late 1993.[5]

CHAPTER 2. SURVEY OF THE USE OF GIS AT US AIRPORTS

INTRODUCTION

The use of geographical information systems (GIS) at airports in the United States is not as well-developed as it is in the highway transportation sector. The objective of this chapter is to determine the extent of the use of GIS at our nation's airports and to identify the potential applications for GIS at airports. The researcher has proposed the concept of an integrated airport GIS that has many uses and users at the airport and provides a sophisticated tool for better airport engineering and management. GIS is a valuable tool that becomes more cost-effective if the cost of the development of the base map and data structures can be spread among several different applications.

A significant contribution of this research was the survey mailed to over 172 certificated airports (airports certified for scheduled passenger service) in the United States and the responses received from more than 80 airports. The major expenses at airports today are the costs of the infrastructure and the mitigation of environmental concerns.

Airports, especially large airports, are essentially small cities in themselves with many of the same management and infrastructure problems of small municipalities. However, there are several unique characteristics related to the operation, regulation, and management of airports that are different from those involved in managing a municipality. Although an airport has a significant infrastructure investment in pavements, the rules and regulations that govern the operations and maintenance of the airfield pavement are significantly different from those for highways and streets. The importance of the runway pavement to the airport can be more critical than the streets and highways are to municipalities and state highway departments.

However, there are similarities. Airports also have streets, and most of the nation's state highway departments are becoming or have already become state departments of transportation. Therefore, it follows that the lessons learned from our municipalities and states that are turning to GIS for better management of their infrastructure, may also be applied to our nation's airports with the same success and enthusiasm.

In the following chapters, some of the potential applications are more fully discussed, and suggested specifications are described that airports can use to provide guidance to develop a GIS that meets the needs of the airport. The most economic gain will come from developing a system that supports many different users. The cost of developing one GIS that supports three different applications should be considerably less in both development and maintenance than the cost of developing three independent, single-application information systems.

In many cases, developing a GIS for one application will require developing a base map that will include all the airfield pavements. If the graphical representation of the pavements is developed into the GIS in accordance with the specifications for a pavement management system, that application could possibly be added to the GIS, essentially almost for free. The other reason for developing the specifications is to let airports know what features and applications can be developed with their GIS at little extra cost.

POTENTIAL GIS USES AT AIRPORTS

There are several potential uses of GIS at airports that are uniquely different from uses with other modes of transportation. Infrastructure management is one use that is somewhat common to both airports and other modes of travel. Included in infrastructure management are management of utilities, leasable space, equipment, and pavements. Airports are businesses; something that generates income or that can save money gets the highest priority. Consequently, management of property and leasable space can become a priority.

The questionnaire distributed to the airports listed 16 potential applications of GIS for airports and asked the responder to indicate if they actually use GIS or planned to use GIS for each application. The questionnaire was developed over a long period of time from the researcher's experience and discussions with several airports and airport consultants. In order to keep the questionnaire simple enough to encourage wide participation, it was limited to a double-sided sheet of paper and is included in Appendix A.

A list of potential applications was provided, but complete descriptions were not given on the two-page questionnaire as to the manner in which the listed application, might be used with GIS. In addition, the "Other" application category was listed with a space for write-in answers. The following potential applications that were listed on the questionnaire can be grouped into three areas:

1. Infrastructure Management
   a. Management of Airport Properties
   b. Management of Leasable Space
   c. Management of Utilities
   d. Management of Airport Pavements
   e. Management of Gates
   f. Management of Aircraft Ground Support Equipment
2. Environmental Analysis or Management
   a. Management of Storm Water or Storm Water Pollution Prevention Plans
   b. Management of Noise Complaints
   c. Noise Contour Calculation
   d. Analysis of Changes in Noise Contours
   e. Noise Monitoring Programs
   f. Management of Off-Airport Properties such as noise mitigation programs
3. Intrinsic GIS Capability
   a. Geographic Analysis of Any Kind
   b. Geographic Display of Raw Data
   c. Geographic Display of Queried or Analyzed Data
   d. Using GIS for Database Error Checking

THE CONDUCT OF THE SURVEY

A survey was mailed in November 1993 to approximately 172 of the certificated airports on the FAA mailing list. Using the Airports Council International (ACI) [6] list of airports reporting their 1992 annual number of operations (take-offs and landings), all United States airports reporting at least 40,000 annual operations were mailed a survey. Other airports on the certificated airport list which were thought to have over 40,000 annual operations were also mailed a questionnaire. The questionnaire was addressed to the Airport Manager or Director of Aviation of each airport, and it was requested in the cover letter that the questionnaire be passed along to the most qualified person for response.

By February 1994, only 64 questionnaires had been returned. A Decision was made that all the airports with annual operations greater than 140,000 which had not responded to the first questionnaire be mailed a second letter requesting them to complete the questionnaire. Approximately 35 second mailings were made, and these resulted in approximately 17 additional airports being included in the survey. Although the second mailing was made only to larger airports, the sample of responding airports is representative for informational purposes.

The survey population consists of 81 responding airports, ranging from a reported high of 840,000 annual operations at Chicago O'Hare International Airport to a reported low of 40,000 annual operations at Danville Regional Airport. The reported acreage within the boundaries of the responding airports ranged from a reported high of 17,637 acres at Dallas/Fort Worth International Airport to a reported low of 176 acres at Key West International Airport, with an average size of 3,211 acres.

The sample size of 81 responses from a pool of 172 airports mailed questionnaires represents a 47 percent return rate. However, there may be some bias in the airport population that returned questionnaires versus airports that did not return questionnaires. An airport that has a GIS system and is proud of the results they achieved may be more inclined to answer the questionnaire than those airports who asked "What is a GIS?" and the researcher did get a few telephone calls asking just that. There may be an additional source of bias in the data from airports who don't really understand what the difference is between a "Smart CAD" with links to a database and a true GIS. From an analysis of the responses, it is possible that some airports think that high-end Computer-Aided Drafting (CAD) programs, which have the capability to display graphics with a link to database information, constitute a GIS in their interpretation.

As reported in Chapter 1, GIS has the ability to perform spatial analysis of the data where a "Smart CAD" program can perform queries on databases and show the results graphically. The bottom line is that some potential airport applications don't require all the features of a GIS, and several users may be confused by the subtle distinction of what a GIS really is; therefore, the results of the survey may have some inevitable inaccuracies. The researcher has not attempted to verify that every airport reporting a GIS, actually has a *true* GIS rather than similar software that performs some of the applications. Any conclusions based upon the findings of the survey should reflect these limitations.

THE FINDINGS OF THE SURVEY

One of the first findings of the survey was several telephone calls from recipients of the questionnaire asking specifically "What is a GIS?". The researcher was surprised to find that many airport managers of the smaller airports had not even heard of GIS. The researcher assumed a higher level of awareness of GIS technology from airport mangers.

The survey asked if the airport is currently using a GIS, plans to use a GIS within 12 months, or plans to use a GIS within 36 months. Of the 172 questionnaires, 81 were returned for a 47 percent response rate, which is considered very good by cold mailing standards. Of the 81 responses to the questionnaire, 47 of the airports (58 percent) said they use or plan to use a GIS within the next 36 months. As shown in Figure 2.1, only 25 percent (20 out of 81) airports actually use a GIS.

Busier airports had a higher response rate and a higher rate of GIS use or planned use. Using the Airport Council International ranking of the top 50 busiest airports in the US in total operations, a 60 percent response rate indicated that 73 percent use or planned to use GIS. Figure 2.2 shows that the actual GIS use rate, survey response rate, and Planned/Actual GIS use increased as the airport population has increased aircraft operations. For example, for the top 25 busiest airports, the 16 or 25 surveys returned indicated that 81 percent of the airports either use or plan to use GIS within the next 36 months.

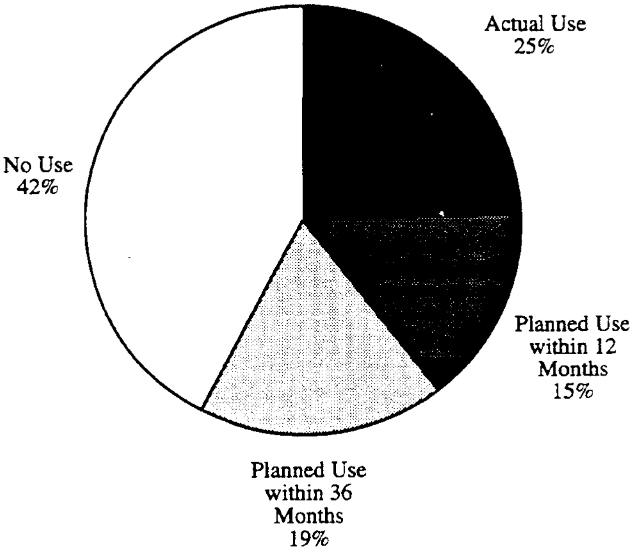

Figure 2.1 Percent GIS Use at Responding Airports

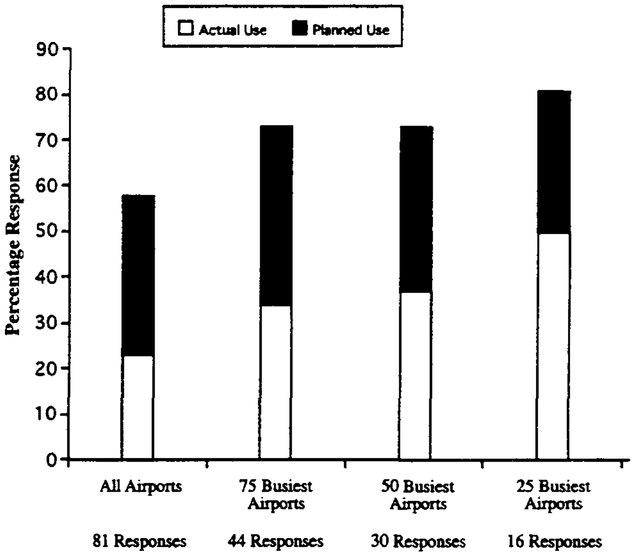

Figure 2.2 Response Rates of Busiest Airports

Even airports that reported using a GIS plan to add more applications for their GIS usage. Table 2.1 lists 17 different potential airport applications for GIS usage. The first column is the rank order of the potential applications, based upon the 47 airports who responded to the questionnaire indicating the applications which they are using or planning to use GIS within the next 3 years. The fourth column shows the percentage of the 20 airports reporting actual GIS usage that are using that particular application for GIS. The second column reports the actual and planned use for those 20 responding airports. For example, in Table 2.1, column 3, it shows that 60 percent of the 20 airports actually use GIS for management of airport properties, but in column 4 it shows that 95 percent of the same 20 airports with a GIS, plan to use GIS for the same application. The fifth column shows that 89 percent of the 47 airports that reported using or planning to use a GIS, plan to use a GIS for management of airport properties.

One interesting application worth noting, management of storm water or preparation of storm water pollution prevention plans (SWPPP), is ranked fifth overall in percentage of planned use, but only at 20 percent in actual usage. One potential reason for this

TABLE 2.1 RANK ORDER OF POTENTIAL GIS APPLICATIONS BY AIRPORTS ACTUALLY OR PLANNING ON USING GIS

Rank	Potential GIS Application	Percent[1] Actual	Percent[1] Plan & Actual	Percent[2] Plan & Actual
1	Management of Airport Properties	60	95	89
2	Management of Leasable Space	55	95	85
3	Geographic Analysis of any Kind	40	70	81
4	Management of Utilities	30	75	79
5	Management of Storm Water or SWPPP	20	80	74
6	Geographic Display of Raw Data	55	75	72
7	Geographic Display of Analyzed or Queried Data	50	80	70
8	Management of Airport Pavements	25	70	70
9	Management of Off-Airport Properties	45	75	66
10	Management of Noise Complaints	45	50	55
11	Integration with a Noise Calculation Program	55	65	53
12	Analysis of Schedule Changes on Noise	20	50	49
13	Using GIS to Check for Database Errors	35	50	47
14	Integration with Noise monitoring Equipment	20	40	45
15	Management of Gates	20	35	30
16	Other	15	25	17
17	Management of Aircraft Ground Support Equipment	10	10	11

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[1] *Based on 20 airports actually using GIS*

[2] *Based on 47 airports actually using or planning on using GIS*

anomaly is that a SWPPP has only recently been required of airports. In fact, the American Association of Airport Executives (AAAE) had filed a group National Pollution Discharge Elimination System (NPDES) permit for airports, but a model SWPPP had not yet been developed. More detailed discussion of SWPPP is found in Chapter 5.

One interesting finding was related to hardware and software reported in the questionnaires. Of those airports that indicated the software they were using, ARC/INFO, Intergraph MGE, and AutoCAD were mentioned most often. The reported numbers and types of computer stations with access to the GIS were predominantly IBM/IBM-compatible personal computers, with a fair amount having workstations. Only two airports reported having more than six GIS computer stations. Only two airports indicated that they had a full-time GIS manager on staff; one other airport indicated that a consultant was hired as full-time GIS manager; and one airport indicated that they planned to have a full-time GIS manager.

Another interesting finding was the responses to the application marked "Other", where space was provided for writing in additional applications for GIS at airports. Some of the submitted GIS applications are rather unusual, and only Project Development was submitted by more than one airport — although several write-in applications are related to the management and tracking of ongoing or planned projects at the airport. Of the write-in applications for airport GIS, management of airport projects and modelling of airport operations will be discussed in Chapters 7 and 8, respectively. Write-in applications included the following:

Emergency Exercises
Planning Development Project Applications
Management of Aviation Easements
Tracking Construction and Design Progress
Automated Work Clearance Requests
Interface With Work Information Management
Runway Critical/Clear Zones
Part 77 Surfaces Overlay
Airfield Inspection
Leases
Lighting Systems
Assessments for Improvements
Airport Layout Plan
Interactive Models for Terminal and Runway Operations
Consultant Selection
Rodent Control

THE CONCLUSIONS AND RECOMMENDATIONS FROM THE SURVEY

Although not as well developed as in the highway community, the use of geographical information systems at airports appears headed for a large increase, both in the number of airports using GIS and in the number of applications supported. Fifty-eight percent of all airports that responded to the survey indicated that they are planning to add applications to an existing GIS or planning to develop a GIS within the next 36 months. Even if all the airports that did not respond to the survey are not planning to add a GIS, 47 airports still represents a sizable amount of work in GIS development over the next three years. All airports which had a GIS, indicated that additional applications were planned. This indicates that GIS usage at airports has not reached a stable level, but is still in a dynamic growth phase.

Four airports indicated that they had or were developing more than one independent GIS. In one case, a very large airport was developing three independent GIS for different applications. Consultants were developing the GIS under contract, using the same specified software, but for separate users at the airport. This could lead to duplication of effort and would lose some of the synergistic effect that a single system could provide to the three users. However, in this case, one system was to manage off-airport properties for a noise mitigation program, and another was to manage utilities, leasable space, and infrastructure on-airport.

Many airports are just getting into GIS or are thinking about GIS and have not yet considered all the applications that GIS could provide. Airports that have commercial airline traffic have a source of funding and are more willing to spend the time and resources necessary to develop a GIS for the potential savings in efficiency that it will provide. Large airports are particularly sensitive to the delay costs to the airlines if portions of the airfield must close. For example, a study for the Dallas/Fort Worth Airport, showed that closing one runway during taxiway construction was so great that a 2-hour savings in runway shutdown time per day over a 4-month construction project saved $4 million dollars in airline operating costs due to delay and justified the use of construction with paving blocks.[7]

From the responses received, it can be concluded that airports are just getting started with GIS and, generally, can see the potential benefits for several different applications. As shown in Figure 2.3, of the 81

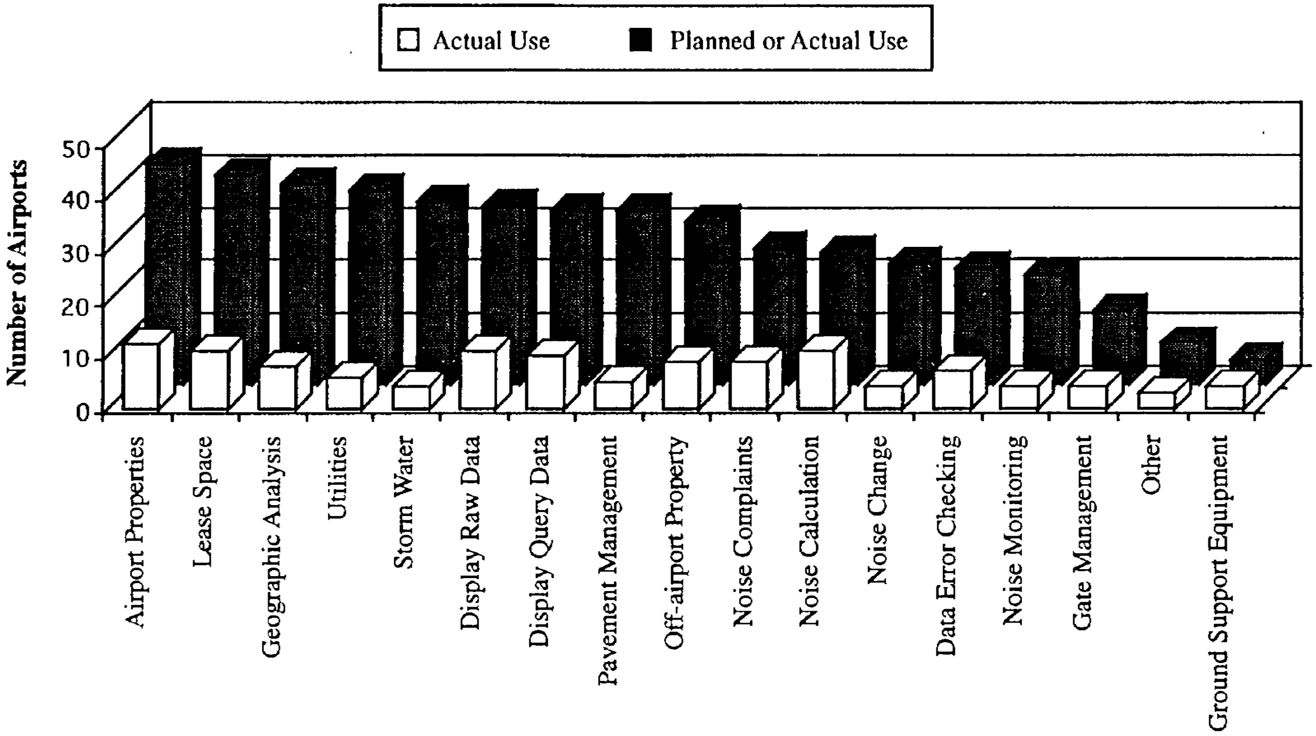

Figure 2.3 Actual and Planned GIS Application Use at Airports

responding airports, the most widely used single application of GIS was seen in 12 airports who use GIS for management of airport property. While this represents only 15 percent of the responding airports, this application grows to 42 airports, or 89 percent of the responding airports, when all airports are included that plan to use GIS for this application within three years. The only potential GIS applications considered that did not receive a 45 percent rating for a planned application were management of gates and management of aircraft ground support equipment. The most probable reason these potential applications were rated so low is that these functions are generally an airline responsibility, and only at the largest and busiest airports would these two applications be considered feasible.

As shown in Figure 2.3, the number of planned applications within three years is far greater than the number of actual GIS applications. For the 17 listed applications on the survey you have 120 actual airport-application combinations. Within the next three years there are 467 planned airport-application combinations. If all the planned airport-application combinations were actually accomplished in the next three years, it would represent a growth of 489 percent of the current level of GIS use at our nation's airports, assuming each airport-application combination were hypothetically of equal value. This would, hypothetically, suggest that airports will develop in the next three years, four times the number of applications that have taken place over the last 8-10 years. Even if less than half of the planned applications are ever implemented within the next three years, the survey indicated that there will be a dynamic growth of airport GIS applications over the next three years.

CHAPTER 3. APPLICATION OF GIS TO AIRPORT PAVEMENTS

Pavements are a significant portion of the infrastructure at airports, both because of their cost and criticality in airport operations. This chapter discusses the specific application of GIS for airport pavement management. The following chapter discusses applications of GIS for other infrastructure management such as the management of lease space and utilities.

In the United States, we spend approximately $2 billion per year for the construction and rehabilitation of airport pavements under the airport improvement program (AIP). This figure does not include the millions of dollars spent on pavement maintenance, which is not federally supported. There are approximately 6,818 airports and heliports in the US identified in the Department of Transportation database.[8] No one doubts the importance of the runways, taxiways, parking aprons, or even the roads and parking lots, to the successful operation of the airport.

The value of the existing airport pavements is a national resource vital to our economy, and preserving that resource is vital to a safe and efficient national air transportation system. The FAA estimates that during the 1990s, of the $40.5 billion that is estimated to be spent on the public use airports in the National Plan of Integrated Airport Systems (NPIAS), $17 billion, or 42 percent, will be spent on constructing, maintaining, and rehabilitating airport pavements.[9] While most of this spending will be concentrated on air carrier airports, the airport pavements at smaller airports are a vital part of this national resource as well.

HISTORICAL DEVELOPMENT OF PAVEMENT MANAGEMENT

Pavement engineering is a science that has evolved primarily from empirical data and experience to more sophisticated design and analysis techniques. Although pavement failures are not as catastrophic as a collapsing bridge, the effects upon airport operations can be just as catastrophic. From first-hand experience, nothing is more important to an airplane pilot than knowing that there is a smooth, safe landing strip upon which to land his aircraft. However, in times of budget crisis, compromises must be made. Therefore, it is of critical importance that the airport operator have a mechanism with which to evaluate the condition of the pavement, estimate and plan for maintenance and rehabilitation actions, and optimize resources in designing, constructing and maintaining airport pavements.

A pavement management system is one mechanism the airport operator can use to optimize his resources while managing the airport pavements. According to Haas and Hudson, the term "pavement management systems" evolved during the 1960s and 1970s from researchers at The University of Texas at Austin, and Texas A & M University, as well as from a group of Canadian researchers who were all looking at a new systems approach to the design of highway pavements as a result of the AASHO Road Test.[10]

Pavement management systems have become popular and vital tools in the management of highway pavements. Many state highway departments have embraced the principles of pavement management and have shown significant cost savings. The Federal Highway Administration (FHWA) has been a big proponent of state-wide pavement management systems for federal highway funding. Congress has recently mandated in the Intermodal Surface Transportation Efficiency Act (ISTEA),that all states must use a pavement management system in order to continue to receive federal highway trust funds. The past experience and success with pavement management systems lead Congress to mandate bridge management, safety management and congestion management systems, although these technologies are much further from a highly developed state than pavement management systems.

Pavement management systems for airports began with research conducted in the 1970s by the Construction Engineering Research Laboratory (CERL) for the US Air Force under the direction of what was then the Civil and Environmental Engineering Development Office at Tyndall Air Force Base (which is now the Air Force Civil Engineering Support Agency).[11] This research led to the development of the PAVER and

MicroPAVER pavement management system. The Federal Aviation Administration has also adopted the methodology of the Pavement Condition Index (PCI) developed for PAVER and encourages airports to use the pavement condition index for condition surveys of airports.[12] The PCI is a visual grading system which collects the amount and severity of all distresses observed on pavements and computes a repeatable index of distress. The FAA will reimburse its share of the cost of a pavement condition survey for master planning and for scoping under the airport improvement program (AIP) for the initial design of a rehabilitation project.

Although the FAA encourages the use of pavement management systems and encourages the use of MicroPAVER software that can be obtained for very little cost, the FAA does not mandate a pavement management system for any size of airport.[13] Each airport must determine whether the development of a pavement management system is cost-effective and will reduce the cost of maintaining the airport pavements.

The US Air Force encourages the civil engineering squadron at each Air Force Base to maintain the MicroPAVER pavement management system, but this has not resulted in widespread acceptance. Even though the MicroPAVER system was specifically designed for justifying the annual budgets for pavement maintenance actions on Air Force Bases, the difficulties in collecting the data, maintaining the system, and getting useful engineering information from the system has hindered implementation. The software problem is most evident because the data architecture was designed under the mainframe computer version of PAVER and does not permit interface to other relational database programs.

PAVEMENT MANAGEMENT NEEDS

In a recent study of the needs of the pavement management system in the Texas Department of Transportation (TxDOT), the following conclusions were presented:[14]

1. The most urgent need of the districts is the production of maps highlighting sub-standard pavement sections.
2. The districts have a need for *graphically* accessing, manipulating, analyzing, displaying, and reporting information on the road network.
3. The top item on the priority list of the pavement management system needs of the districts is the automated production of graphics output in the form of maps to convey information on the highway network.

These conclusions are all functions that can be achieved using a GIS integrated with the pavement management system. Several states have integrated their GIS and pavement management systems or are in the process of combining them at this time. However, the larger the area and the more lane miles of pavement in a pavement management system, the more difficult it is to convert to a GIS-based system.

Implementation of pavement management systems has been a long, slow process — and GIS implementation is also a long, slow process for large government organizations that have no profit incentive to change. In a recent conference on GIS for Transportation in Norfolk, Virginia, 43 states, provinces, and the District of Columbia transportation departments reported activities related to GIS and the road network in their state.

GIS FOR PAVEMENT MANAGEMENT

GIS and pavement management have been considered as complementary for several years. Since transportation features are prominent in nearly all GIS and since in many states the transportation department also serves as the state cartographer, it is natural to consider a GIS for pavement management. In the case of Wisconsin, the GIS and the pavement management system were actually developed together. In Wisconsin, a committee formed for developing a Pavement Management Decision Support System mandated that the system be developed to include the following features:[15]

1. Expert system to analyze pavement problems and recommend rehabilitation strategies.
2. Spatial data concepts used in design of a large decision support database.
3. Spatial analysis routines to integrate pavement inventory, performance, and management data.
4. GIS display and cartography tools used to portray complex relationships among many decision elements.
5. Development of dynamic cross sections constructed from project inventory data.

THE NEED FOR GIS IN AIRPORT PAVEMENT MANAGEMENT

In many of our nation's airports, the capacity problem related to the number of operations per runway is a major issue that makes the cost of closing runways for maintenance or repairs difficult. One of the reasons for GIS in airport pavement management is to help reduce the direct and indirect costs associated with construction, maintenance, and rehabilitation of airport pavements.

One documented use of GIS for airport pavement management was for the New York and New Jersey Port Authority, which hired a consultant to develop the pavement management system for the three airports (JFK, La Guardia, and Newark); the consultant used GIS to graphically display the pavement condition data.[16] As previously reported, just as highway engineers' highest priority is a method of showing the areas of substandard distress, so are airport pavement engineers' desires to do the same.

It is difficult enough for pavement engineers at the larger airports to keep up with the current demands for maintaining the runways, taxiways, and aprons, because the existing pavements are mostly all over 20 years old, and they are receiving more and heavier loads than they were actually designed to carry. Although the Micro PAVER software does not provide the means for collecting and analyzing variables such as traffic, environment, or pavement structural capacity, a complete pavement management system must account for these variables, especially in light of the dynamic growth of aircraft traffic. It is difficult to take the time to assess the condition of the runway and other pavements, and even more difficult to accurately forecast future requirements.

The key to proper management is correctly analyzing the data. To understand the problem, one needs to see the effects and visualize the relationships. GIS is excellent for integrating mountains of tabular data, displaying it with geographical relationships, and allowing the engineers and decision makers to make queries. A GIS facilitates the interaction of environmental or traffic data with pavement data for a more complete analysis.

The next step in pavement management is to prioritize resources and pavement rehabilitation strategies. Optimization of pavement performance or pavement life is usually what a pavement management system is designed to achieve. For airports, the optimization routines might be slightly different to optimize runway utilization time. Regardless of what optimization strategy is used, there is a need for a measurable result. There is no better way to compare the results of the potential budgets for alternatives than to have a visual display of the comparative forecasts. GIS can be both an analysis tool for pavement management and a management tool for administrators.

The principal reasons pavement management systems have not been very popular or effective at airports is that the FAA-endorsed MicroPAVER program does not provide immediate cost/benefit gain above the painstaking data collection process and the work required to operate the software, nor has it kept up with current technology. The pavement condition index developed in the 1970s for airports does an adequate job of quantifying the distresses observed on the surface for airport pavements. But new technology has been developed for ground penetrating radar (GPR), falling weight deflectometer (FWD), and spectral analysis of surface waves (SASW) which go beyond that which is observed on the surface. Additional new developments in the imaging of pavements and the analysis of surface roughness have great potential for analysis and prediction of pavement performance.

As the characterization of pavement materials and the constitutive behavior of pavements are better defined by future research for airport pavements, there will be an increased need for better evaluation of pavements. What is needed to analyze or manage the pavement is a computerized system that provides a common location reference system, is capable of coordination with multiple databases, can visually display data and information, and can perform spatial analysis.

The best common location reference system to use would be a geographical location. Differential Global Positioning System (D-GPS), which is being implemented at airports for precision approaches, can supply the accuracy needed to locate any collected data (roughness, distress, or NDT) in real time to an accuracy less than 25 cm. Graphic visualization of data and information is necessary for understanding, analysis, and presentation of results for complex airport pavement systems. Integrating multiple databases on multiple platforms is a necessary function that can be performed by a geographical information system. GIS by definition have the ability to integrate databases, display information graphically, and perform spatial analysis.

EXAMPLE GIS FOR AIRPORT PAVEMENT MANAGEMENT

As a demonstration of the ability of GIS to be used for airport pavement management, a small demonstration GIS was developed using Robert Mueller Municipal Airport in Austin, Texas, as the subject. Intergraph Modular GIS Environment (MGE) software was used both on the personal computer and on the Intergraph UNIX workstation to develop the GIS.

Intergraph MGE is the cornerstone of a suite of GIS tools that are used to achieve full GIS functionality. A complete Intergraph GIS includes a relational database (Oracle, Informix, or Ingress for UNIX and Oracle or dBase for the PC), MicroStation as the CAD program providing the graphic engine, and MGE or MGE-PC as the integrated GIS. Additional modules are often necessary, such as Modular GIS Analyst (MGA) to perform a vector data type of spatial analysis, and Projection Manager, which is necessary to project a vector data type map. Projection Manager and MGA are not available in the PC DOS version, but are available in the UNIX workstation version or in the PC Windows NT version.

The base map for this demonstration GIS was developed from the latest version of the airport layout plan (ALP)

prepared for the airport by a consultant in AutoCAD format. The drawing number 023-25, dated September 30, 1992, shown in Figure 3.1, was imported directly into MicroStation PC version 4.03.01 using the DWGIN utility without any problems.

The different cultural elements in the drawing were divided among several different levels in the MicroStation drawing (layers in AutoCAD drawings). The base map need not include extraneous information, so some of the required elements on the ALP drawing such as the border, the wind rose, and the tables were simply deleted using the CAD tools in MicroStation. The intention was that not all the graphic elements needed to be converted into topological features and categories (coverages in ARC/INFO). All graphic elements were kept that provided information about relative locations on the airport, but only some of those elements were chosen to become topological features. The remaining graphic elements can remain visible or can be hidden as necessary for geographic visualization.

GIS WORKFLOW

The Intergraph MGE PC-1 documentation includes project planning worksheets and a suggested workflow for starting a project based upon whether or not the database and graphics already exist. For this example, the suggested workflow for a system with existing graphics and no database was followed. The abreviated workflow is listed below and the complete suggested workflow is included in Appendix D.[17]

I. Preliminary Steps:
II. Set up the Project:
    1. Create the project.
    2. Create database schema.
    3. Define project schema.
    4. Create categories and indexes.
    5. Create and define features.
    6. Create user-defined attribute tables.
III. Add Graphic Data to Project:
    1. Set up seed file; define coordinate system.
    2. Move graphics to "project\dgn" directory.
    3. Make features from graphic elements.
IV. Ensure Data Integrity:
V. Load the Database:
VI. Verify and Update Project Data:
VII. Access Project Data:
    1. Create geographic indexes.
    2. Create a vicinity map.
    3. Locate non graphic data.
    4. Locate graphic data.
    5. Change the active map.
    6. Select features to be displayed.

PROJECT PLANNING

Intergraph provides project worksheets that assist in the project planning by helping to determine which features need be created. The worksheet provides space to plan for the type of feature (points, lines, area boundary, and area centroid), the name of the category, and the feature level (1-63 similar to named coverages in ARC/INFO).

For the pavement management application, the pavement condition index (PCI) for Runway 13R-31L was collected from a report provided by an airport consultant responsible for a recent runway repair. The pavement condition index is 100 for a pavement without any visible manifestation of distress. Over time and loading, as cracking and other distresses become evident, the pavement is visually surveyed, distresses recorded, and points are deducted from 100; then a PCI is computed. A pavement with a PCI of 85-100 will, generally, not require any treatment, while a pavement with a value of 40-70 may be in serious need of repair or rehabilitation. The FAA uses the PCI value as inputs to the MicroPAVER pavement management system. However, the MicroPAVER system is a self-contained system without any means to graphically display the relationship or locations of sections or their PCI values.[18] Additional pavement roughness data were collected by the researcher on Runway 13R-31L using the TxDOT laser profilometer during a period of runway closure at night. A present serviceability index was computed for 200-foot by 50-foot sections in the center wheel paths and northern edge of the runway.

The items that need to be recorded for each section of pavement are the PCI value, the date, and the distress types (numbered) and severity levels. This information, in advanced applications of MicroPAVER, can be used to develop strategies for rehabilitation or priorities for maintenance and repair.

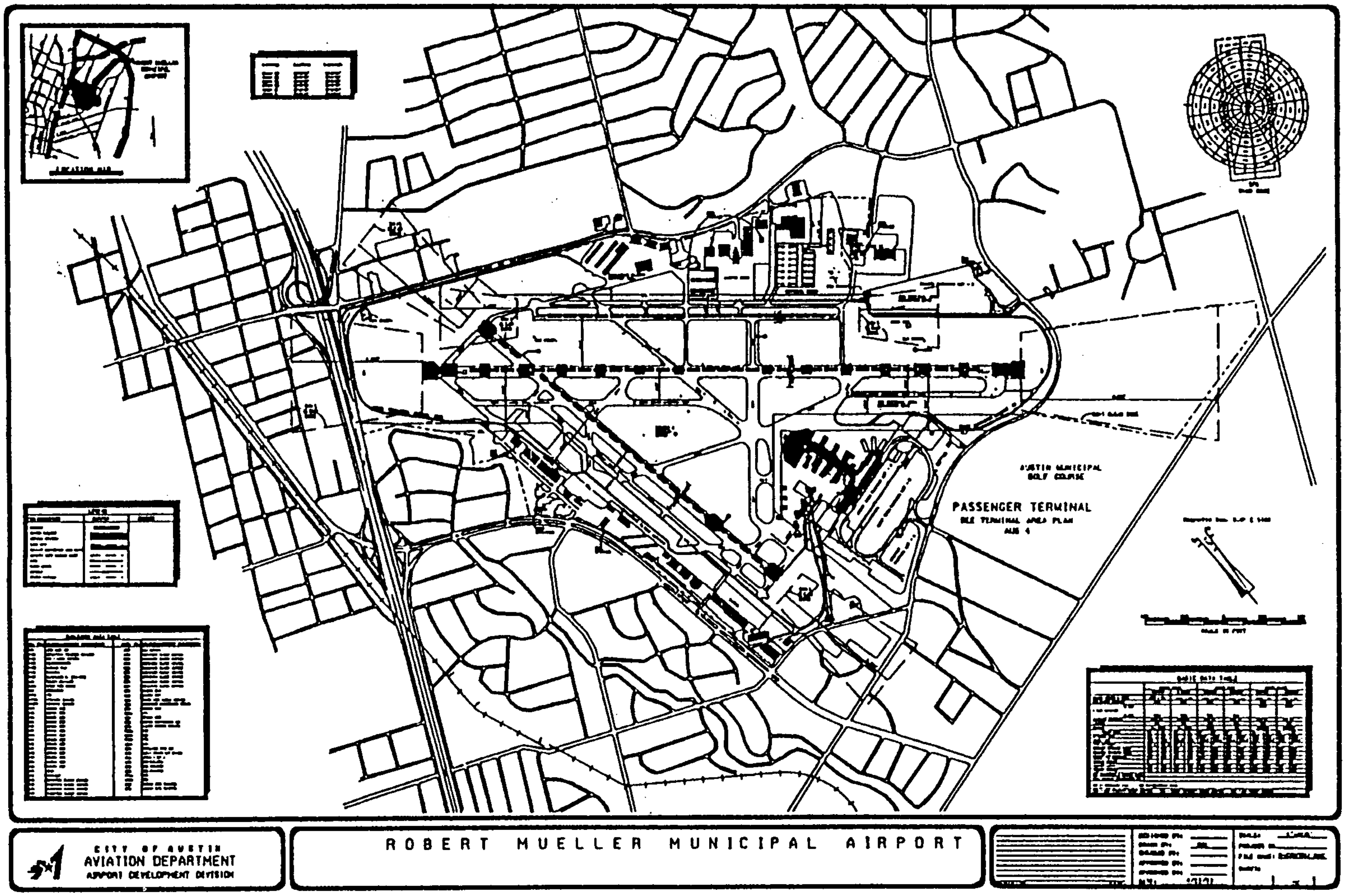

Figure 3.1 Original Robert Mueller CAD Drawing

However, one of the important functions that a GIS can perform is just providing a graphical display of the PCI level or the locations of different types of distresses. Certain areas of the airfield may be getting slippage cracking and other areas may be getting rutting. Advanced spatial analyses could be performed with a GIS to determine whether the areas of certain distresses are more prevalent in areas with older pavement, areas of heaviest traffic, or areas with poor drainage. This could be an important part of the management of the pavements, because it has been estimated that there are over 120 different variables that affect pavement life. Therefore, pavement life or pavement performance is rarely a straightforward analysis, but rather a study of multiple variables and, most importantly, the interaction of the variables.

The procedures for using the MicroPAVER system require that the airfield pavement be divided into families such as aircraft runways, aircraft taxiways, aircraft parking ramps, and roads for vehicles. Each runway, for example, would be a separate branch in the runway family. Each runway would be divided into different sections. The recommended method is to divide asphalt pavements into sections of 5,000 (± 1,000) square feet and concrete pavements into groups of 20 (± 10) slabs. These recommendations are not mandatory, and serious consideration should be given to actual section sizes. Also, consideration should be given to making a division between sections where there is non uniformity such as runway extensions which were constructed much later.

For the Robert Mueller Airport demonstration, data were available for the asphalt air carrier runway, which was known to have some distress and roughness concerns for the airport. Using the graphic tools in MicroStation, 50- by 200-ft sections were drawn on a separate level, precisely overlaying the runway. The boundaries of these sections were digitized, copied, cleaned, and turned into area boundary features, with centroids placed in each section.

Text identification numbers were placed into each section as shown in Figure 3.2. It would have been possible to have the centroids identified as text rather than as points, which may have saved a step and some storage space.

The feature maker screen in MGE was used to make and define the levels, symbology, color, and line weight for 18 different features to be made for the demonstration GIS. The runway table was created in MGE for Oracle using the menus provided in the table builder screen in MGE. The table was built to include a graphic link to the elements, with a map ID column in the runway table.

Present serviceability index (PSI) data were computed for each of the 200-foot sections and entered into the database. The demonstration project was completed when both the PCI data showing surface condition from a consultant's report and the PSI data showing profile roughness were loaded into the runway table and the runway sections were individually linked to the database. After completion of these steps, it was possible to provide displays of pavement sections as shown in Figure 3.3 which highlight sections of high distress or high roughness using database queries employing the query builder menu.

The limited demonstration GIS was completed by digitizing pavement sections for only the main runway and creating a topological file for the runway section polygons. A few additional features were created for taxiways, aircraft parking ramps, the runway overrun, and the roads on the property. The only sections of concrete pavement at Robert Mueller Airport are those used for aircraft parking in the gate area, as shown in Figure 3.4 which has been placed to correct a previous pavement failure caused by the movement of the passenger loading bridges. Some of these slabs were also grouped to form sections, but no data were collected.

SPECIFICATIONS FOR AIRPORT GIS FOR PAVEMENT MANAGEMENT

1. The pavement database must be structurally compatible with the MicroPAVER database and have as a minimum the number of fields, field lengths, and data characteristics listed in Appendix B.
2. The database must provide the capability to collect all distress data for the pavement condition index, and the software must compute the PCI for each section. The system must be capable of analyzing which sections have similar types of distresses.
3. The system must provide a means for collecting and analyzing other pavement data not required in the MicroPAVER system, including present serviceability index, international roughness index, back-calculated modulus of elasticity for four layers, and coefficient of friction.
4. The system must provide a means for collecting traffic and environmental data for potential spatial analysis related to pavement performance.
5. The pavement sections will be georeferenced to a horizontal accuracy of 1 to 3 meters. The system will permit location of sections in the appropriate coordinate reference systems selected by the airport, including any local reference systems or map grid coordinate systems required for emergency response or dispatch. Horizontal accuracy requirements are always a judgment upon

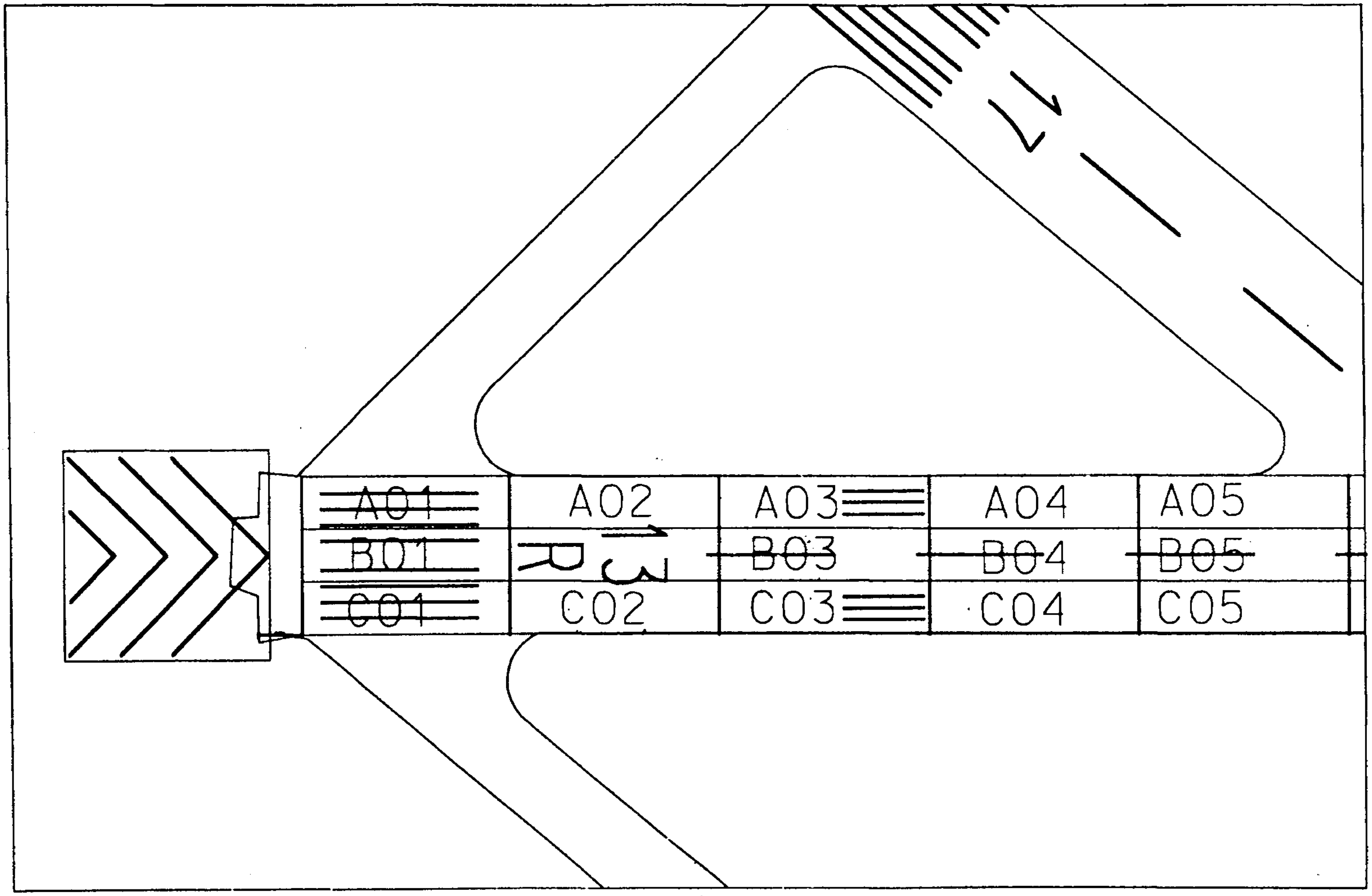

Figure 3.2 Portion of Runway Section Digitized

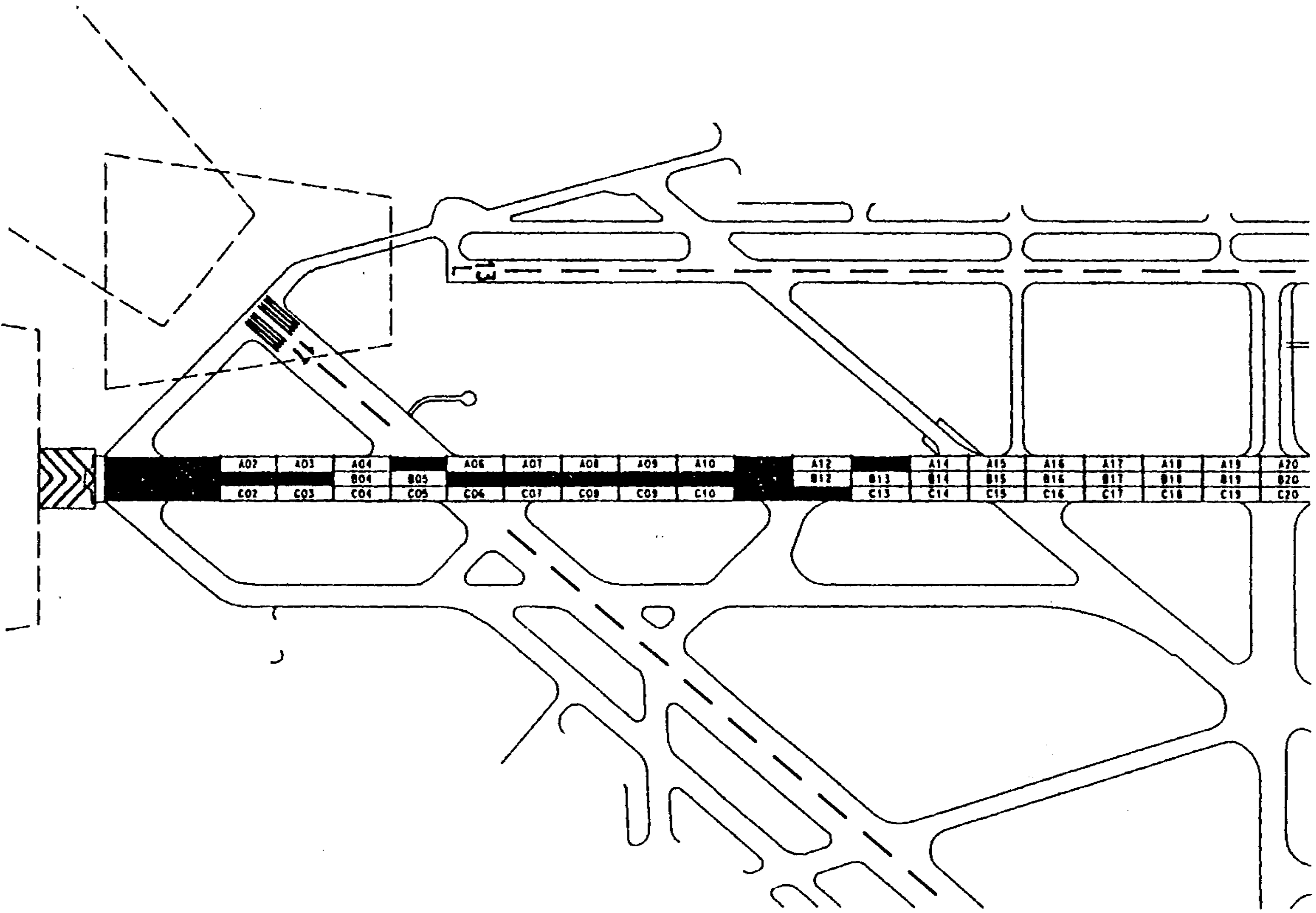

Figure 3.3 Example of Display of Runway Distress

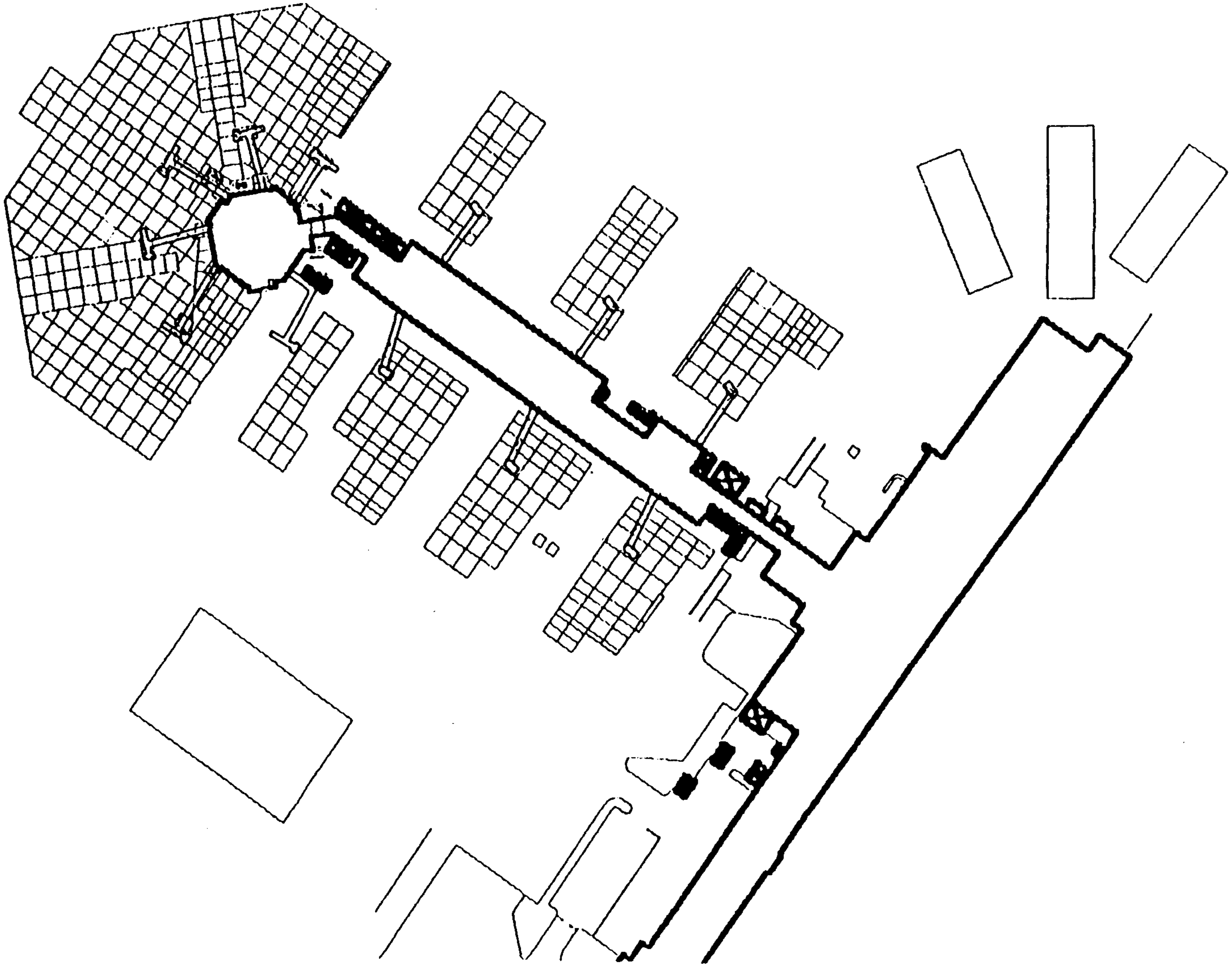

Figure 3.4 Concrete Slabs in Airport Parking Apron

how the GIS will be used. Typical maps have a horizontal accuracy to a coordinate system of 15 meters.

6. If differential GPS positioning is planned to be used at the airport, the pavement sections located within the aircraft movement area should be georeferenced with a horizontal accuracy of 30 cm.
7. The system will be capable of displaying additional images in the background to the vector-based map, such as scanned aerial photographs or digital orthophotos.
8. The system should be compatible with existing relational databases and existing CAD drawings used by the airport.
9. Topological features must be developed for runway, taxiway, and apron features such that spatial analysis can be performed with layers of storm water data, drainage data, and soil condition data, as well as aircraft traffic data.
10. All pavement attribute data for pavement inventory, distress, condition, roughness, and skid resistance will be graphically linked to the proper pavement sections.
11. The GIS must be capable of performing the following spatial operations: (in the absence of specifying specific software, the spatial operators that are likely to used should be specified).
12. Consideration should be given to the question of whether or not the airport requires the software to perform dynamic segmentation. This function is popular in GIS for highways, but may not be necessary for airports unless the airport expects to do a number of field inspections other than distress surveys for pavement condition index.
13. The airport should specify the numbers of users, the number of hardware locations, the type of network to connect the computers, and the types of output devices needed.
14. The GIS must support metrication.

SUMMARY

Pavement management has been successfully integrated with GIS at several state highway organizations. The needs of airports for pavement management include the following items:

1. The need to visualize the condition of the pavement.
2. The need to determine what the relative change in the condition of the pavement system and individual segments of the system has been over time in relation to time, traffic, environmental variables, and maintenance budget.
3. The need to analyze the system for cost effective rehabilitation strategies and prioritize resources.
4. The need to forecast pavement life expectancy relative to all variables including time, traffic, maintenance practices, current distress, structural adequacy, and operational characteristics related to profile roughness and skid resistance.
5. The need to keep a common reference system for locating pavements and pavement distress.
6. The need to correctly integrate large volumes of data with sufficient detail to make engineering decisions about rehabilitation and proper corrective actions.

The demonstration GIS of Robert Mueller Airport successfully allowed the visual presentation of pavement condition index (PCI) and roughness measured by pavement serviceability index (PSI) of the air carrier runway. The visualization of the attribute information in relation to adjoining taxiways and adjoining pavement sections permits a better understanding of the state of the pavement and makes an effective presentation to decision makers.

Specifications were developed for airport GIS related to pavement management including recommendations of database structure, horizontal accuracy, compatibility with imaging and CAD software, feature requirements, and spatial operations requirements

CHAPTER 4. APPLICATIONS OF GIS FOR OTHER INFRASTRUCTURE MANAGEMENT

An entire industry has developed having to do with the management of facilities or infrastructure. AM/FM International is an industry organization formed to assist and educate others about the the automated mapping, facility management industry. There are many custom-designed software products designed specifically for the infrastructure or facility management industry. The utility industry is one of the largest users of GIS, primarily for the management of their electric, gas, water and petroleum infrastructure.

This chapter follows the management of the pavement infrastructure at airports discussed in Chapter 3. Although pavements are one of the major infrastructure features at airports, there are several others which should be considered for management using a GIS. This chapter describes two actual pilot projects underway for the potential application of GIS for the management of lease space and the management of utilities. Both of these items were identified in the airport survey in Chapter 2 as having high potential for GIS implementation.

APPLICATION OF GIS FOR MANAGEMENT OF LEASE SPACE

At US airports nearly all the space is leased to airlines, concessionaires, or other tenants. Lease space is one of the most important sources of revenue for an airport, and any software or system that can potentially improve revenue is usually worth investigating. A recent article in *Geo-Info Systems* magazine describes a pilot project underway at Boston Logan International Airport to integrate GIS and management of lease space.[19] Some of the findings are summarized here to elaborate on this potential application of GIS at airports.

The Massachusetts Port Authority (Massport) rents space to most of the 350 companies that operate at the two airports it regulates, Logan International Airport and Hanscom Field. In 1988, Massport developed a Space Administration and Management Information System (SAMI) using a relational database to track over 500 leases and operating agreements at the airports.

The SAMI system was used to track the information necessary to manage these business agreements. This information included the company name, lease space, lease rate, term of lease, contact names and addresses, and other attribute data. A separate attachment to each agreement was the leased-premises exhibit, which was a manually drafted document displaying the space actually leased. With the high volume of changes, the airport business office started having difficulty keeping the leases current. The requirement to manually provide leased-premises exhibits with accurate square footage was draining the resources of the system and jeopardizing the timely negotiation of agreements and accurate billing statements.

In 1991 Massport decided to add a graphic component to the management system. After internal study, it was decided to use AutoCAD as the Graphic engine, Oracle as the relational database, and Geo/SQL as the integrating GIS for the spatial component. A consultant was hired to complete the pilot project for Terminal C. The pilot project included creating new CAD drawings, designing the relational database, developing the location identifier system, converting the database into Oracle, and developing a customized user interface. The resultant system is called the Tenant and Property Management Information System (TAPIS).

The system was highly successful because it satisfied the needs of many users, including: improved productivity and communication, improved accuracy of the data, and the capability to visually see the space available and make analyses of alternate plans for the customers very quickly. Currently, the system is being expanded for all the lease space for both airports, and other departments are finding applications for using the data available about the space on the airport.

While not all airports have as many lease agreements as Boston Logan International Airport, even smaller airports can be candidates for using GIS for management of the lease space. Any airport with a significant amount of lease space or other infrastructure could justify a small GIS system, if there are frequent changes to the data, multiple tenants or customers, and/or multiple users of the data, and if the use of the data can be enhanced by visual presentation. Another important reason for keeping lease information current relates to potential EPA enforcement actions against the airport operators based upon the actions of the tenants with regards to compliance with storm water pollution prevention plans.

The perceived advantage that the application of GIS for management of lease space may have over pavement management for a potential implementation of a GIS is really a misconception. Airport authorities see lease space as part of the income revenue stream and tenants as customers. However, they often fail to see that the outgoing revenue stream is just as important and that the airlines and the airport itself are the customers of the maintenance or engineering department.

APPLICATION OF GIS FOR MANAGEMENT OF UTILITIES

Dallas/Fort Worth International Airport issued a contract to develop a GIS to manage lease space on the airport and maintain an inventory of underground utilities. The issue that drove the pilot project underway at DFW was related to construction for tenants. It seemed that often, when a construction contract was let to build to suit the leasing tenant, there had to be an expensive change order because the underground utilities were not located where the old maps, if indeed there were any, indicated they were.

The development project in progress for Dallas/Fort Worth International Airport involves developing a GIS to manage lease space. In addition the same contract will map all utilities on the airport. The contract was developed to rely on company provided location information for the electric and telephone lines. However, the information on airport owned utilities such as sewer and water will be field verified and detailed management information as to condition will be maintained.

One of reasons that GIS is so popular with public utilities is that it permits graphic visualization of what can't otherwise be seen. The use of the Global Positioning System (GPS) is also popular with a GIS for utility management, because there often are not any visible landmarks to determine one's precise position.

The advantage of using a GIS instead of only CAD mapping is that spatial analysis can be applied when necessary to indicate all features or specific features located with a reference distance of the utility line. If a water line should break the features located within a specific distance can be identified easily.

SUMMARY

This chapter described two actual pilot projects under way for the potential application of GIS for the management of lease space and the management of utilities. Boston Logan International Airport uses GIS for management of its lease space including AutoCAD as the Graphic engine, Oracle as the relational database, and Geo/SQL as the integrating GIS for the spatial component. The system was highly successful because it satisfied the needs of many users including: improved productivity and communication, improved accuracy of the data, and the capability to visually see the space available and make analyses of alternate plans for the customers very quickly. Any airport with a significant amount of lease space or other infrastructure could justify a small GIS system, if there are frequent changes to the data, multiple tenants or customers, multiple users of the data, and the use of the data can be enhanced by visual presentation.

Dallas/Fort Worth International Airport is developing a GIS to manage lease space on the airport and maintain an inventory of underground utilities. One reason was to determine better locations of underground utilities to save money related to construction for tenants. The use of the Global Positioning System (GPS) is also popular with a GIS for utility management because there often are not any landmarks to indicate position.

Infrastructure management is a potential application for airport management that may have visible savings in the revenue stream. All types of infrastructure management are applicable for GIS if they have a geographic location, changes are often made, or maps or data must frequently be reviewed.

CHAPTER 5. APPLICATION OF GIS FOR AIRPORT STORM WATER POLLUTION PREVENTION PLANS

Airport drainage has always been a concern mostly to prevent the pooling of water on airport pavements. However, recent federal and state regulations have raised the level of concern of storm water drainage. This regulating has made the management of storm water a requirement. It is proposed that the management of storm water be considered as an application of GIS at airports.

THE REQUIREMENT TO OBTAIN PERMITS AND PLANS

In November 1990, the Environmental Protection Agency (EPA) issued its final rules regarding National Pollutant Discharge Elimination System (NPDES) permits (40 CFR, Section 402) for storm water discharges from municipal and certain industrial activities. The EPA rule for issuance of permits for storm water discharges associated with industrial activity, including those for airports, was recently codified by a court ruling which requires the issuance or denial of permits by October 1, 1993.[20] All airports with standard industrial code (SIC) 45 must have applied for permits by April 1, 1993, and most airports either have applied for a general permit under the group application sponsored by American Association of Airport Executives (AAAE) or have applied for individual permits.

As a new development, the multi-sector general permit (MSGP) has become a third choice among available permits from EPA. There may be some advantages for certain airports to abandon their general permits and apply for a multi-sector general permit, because the threshold requirements for sampling are based upon the amount of deicing fluid used, rather than on the number of flight operations. Permits must be applied for either from the EPA directly or from required state agencies in those states where the EPA has designated the responsibility to a state agency. Regardless of which permit has been received, all permits will require the preparation of a storm water pollution prevention plan (SWPPP). It must be pointed out this SWPPP requirement is in addition to the SWPPP required for any construction which disturbs more than 5 acres of soil.

Part of the EPA requirement is the preparation and implementation of a storm water pollution prevention plan which must be approved and signed by the highest authority at the airport and retained on site for inspection by EPA. For the general permit, airports with over 50,000 annual flight operations require annual sampling of outflow during a period of de-icing operations to determine compliance with the permitted discharges.

AAAE has recently prepared a sample SWPPP which can used as a model for other airports and as a guide in the preparation and update of individual plans. However, because of copyright restrictions, the sample plan is not available to consultants, but only to member airports. The FAA is preparing a new FAA Advisory Circular that will also provide a sample SWPPP which can be used as a guide in the preparation of the SWPPP for each specific airport.

MINIMUM SWPPP REQUIREMENTS

On January 27, 1993, in Dallas, AAAE conducted a workshop on Storm Water Permit Compliance, and several recommendations were made as to what the sources of pollution are and what are the necessary ingredients in a SWPPP.[21]

The sources of storm water pollution on airports are:

Aircraft/Ground vehicle fueling,
Aircraft/Ground vehicle maintenance,
Chemical and fuel storage and transfer areas,
Aircraft and runway de-icing,
Aircraft/Ground vehicle washing,
Combined sewage overflow, and
On-site sewage disposal systems.

The data collection required for storm water management includes the following items:

A site map,
A topographical map,
Descriptions of significant material handling activities,
List of pollutants with the potential to be present,
The size of the airport,
The percentages of impervious area,
A history of spills, and
A summary of existing sampling data.

The requirement for a SWPPP include all of the following items:

Identify all potential sources of pollutants.
Identify all potential areas of pollutant contact.
Identify drainage areas.
Identify storm water conveyance and discharge structures.
Identify and eliminate illicit connections.
Identify existing best management practices.

The required site map must include the following items:

Storm water conveyance and discharge structures,
Storm water drainage area for each discharge point,
Impervious cover (paved area and buildings),
Areas of actual or potential pollutant contact,
Location of existing storm water structural controls, (i.e., earth berms, coverings, etc.),
Areas of existing and potential soil erosion,and
Vehicle service areas.

One of the important ingredients of implementing the SWPPP is the implementation of the best management practices (BMP). Mostly, these are common sense practices that are necessary to eliminate or reduce pollutant loadings in storm water discharges from the airport property. BMPs are all measures taken to prevent or mitigate the causes of storm water pollution. They can be simple standard operating procedures, schedules of inspection, training, or prohibited practices. Basically, the minimum requirement for baseline BMPs include the following items:

- Good housekeeping,
- Preventative maintenance,
- Visual inspections,
- Spill prevention and response,
- Sediment and erosion prevention,
- Traditional storm water practices,
- Employee training, and
- Record keeping and reporting.

Another important item in the SWPPP is the identification and elimination of illicit connections from the storm water system. It is important that drains that are used for cleaning actually drain into the sanitary sewer system rather than into the storm water system. The two most important thrusts of the SWPPP for airports are to reduce the flow of deicing chemicals used either on aircraft or on runways into the storm sewer and to clean up all fuel/oil spills to prevent these spills from reaching tributary waters. But an important practice, although generally less of a threat to the environment, is to eliminate illicit or illegal activities such as washing vehicles or aircraft and having the runoff enter the storm sewer system.

Illegal activities such as these, misrepresentations in the SWPPP, or discharges above the permitted amounts can lead to fines and, in some cases, imprisonment. Although the airport is the owner and many tenants actually use the airport property, the airport owner is ultimately responsible for compliance with the SWPPP and for keeping discharges within permitted levels. It is suggested that all tenants either become co-applicants in the permit or file for separate permits. The EPA recommends co-applicants, but the airport operator is responsible for seeking coverage.

In some cases, industrial activities with SIC codes 20-39 may be located on airport property, but require an even more restrictive SWPPP and reporting procedure to the EPA. If that is the case, the airport should become a co-applicant with the industry in that watershed or address the more restrictive requirements in the airport's SWPPP.

As has been shown, there can be many separate watershed areas on the airport property that have either different tenants with primary responsibilities for their areas, or different reporting and monitoring requirements. The more complex the airport, the harder it becomes to visualize areas of responsibility and appropriate responses. As lease holders change, the SWPPP must be kept up-to-date and new tenants must sign the SWPPP and be trained in the BMPs.

APPLICATION OF GIS FOR SWPPP

It is proposed that, even though a GIS is not necessary to comply with EPA guidelines for the storm water permit, all of the required items in a SWPPP can be stored and displayed in a geographical information system. Using a GIS will permit better visualization of the data that is being managed and could help to better implement the plan. If the base map of the GIS has been developed for another application, why not use GIS as a tool for maintaining and monitoring compliance with the permit? Also, if a SWPPP and drainage plan are going to be prepared, why not use that project to implement GIS?

To combat the "out of sight is out of mind" syndrome, a GIS will help keep the requirements visible as well as help explain the problems associated with compliance to decision makers and administrators of the airport. A GIS will also help managers determine whether required inspections and training are being updated. A graphic output of fuel spills will aid in visualizing where the areas of spills are occurring and who is responsible.

EXAMPLE GIS FOR SWPPP

To further demonstrate that a GIS for an airport could accomplish multiple functions rather than having multiple GIS platforms or systems, information required for a SWPPP was added to the same base map used in Chapter 3 for pavement management at Robert Mueller Airport. In addition to the airport layout plan (ALP) drawing, an AutoCAD drawing of all the elevation contours for the airport was also obtained. The AutoCAD drawing of elevation contours was quite large, with 60,438 vertices, and used over 2 Mb of storage space in the AutoCAD format. It was imported into MicroStation PC, which converted some of the vertices into lines and line strings, reducing the file down to 20,872 elements and requiring just over 1 Mb of storage space. The drawing of the contours of the airport is shown on the airport in Figure 5.1.

Using the ALP for location reference, the researcher drove around the perimeter of the airport property locating all the areas where storm water discharges occur. Using the drawing of elevation contours, it was possible to divide the airport into 18 subwatersheds, each with its own discharge from the airport property. In MicroStation, using the base map as the main file and the contours displayed as a reference file, it was possible to heads-up digitize the 18 subwatersheds. As shown in Figure 5.2, the airport is situated between Wilbarger and Boggy Creeks and has drainage into both watersheds. The airport is on relatively high ground and does not have any significant external storm discharge onto the property.

In creating topology for a GIS, the graphic or CAD features must be cleaned to have intersections of objects physically joined, excess vertices removed, and overshoots and undershoot lines joined. The boundaries of the subwatersheds on the base map were "heads-up" digitized, by using the "place line string" command. When an attempt was made to thin out the vertices using the Line Weeder function, it was not as successful as had been hoped.

Line strings, as complex elements, do not lend themselves to the line cleaning process, even manually. The problem was resolved by manually re-digitizing over the display of the line string level by manually placing lines and arcs (curved lines) on a separate level. These lines and arcs were then manually cleaned by using the MicroStation Command to extend a line to intersection, extend two lines to intersection, and modify arc.

Later, the discharge structures and berms required for the SWPPP were added to the map. The buildings and all the additional paved areas of the airport, which are the area of impervious cover, were already identified on the map. Using the GIS, it was possible to calculate the percentages of impervious cover for each of the subwatersheds. MGE has a centroid placer function which will automatically place the centroid of each of the subwatersheds. From observation, few, if any, of the subwatersheds have dedicated stream paths. If additional analysis required a Synder unit hydrograph to be calculated, it could be approximated for small areas using the distance from the centroid directly to the discharge points of each of the subwatersheds.

One advantage of performing this analysis is that some of the subwatersheds have little or no potential for storm water pollution. The EPA ruling allows that the property can be divided into separate watersheds and that those without significant pollution potential can be eliminated from the requirements of monitoring.

The possibility of using the data from the GIS as inputs to the HEC2 storm water analysis modeling was investigated. However, Robert Mueller Municipal Airport really has no major water flows or streams within the airport property, and neither the researcher nor the engineering staff at the airport could see any need for the results. The EPA requires that the signature for compliance with the storm water pollution prevention plan and requirements be accomplished at the highest level of the governing authority, such as the Mayor of Austin for Robert Mueller Airport. Also, since the airport is city-owned, the airport must also comply with the requirements of the City of Austin's SWPPP.

The best possible use of the airport GIS for water runoff is in consolidating the requirements of the storm water pollution prevention plan and using the GIS to document and display the compliance with Federal EPA regulations and rulings.

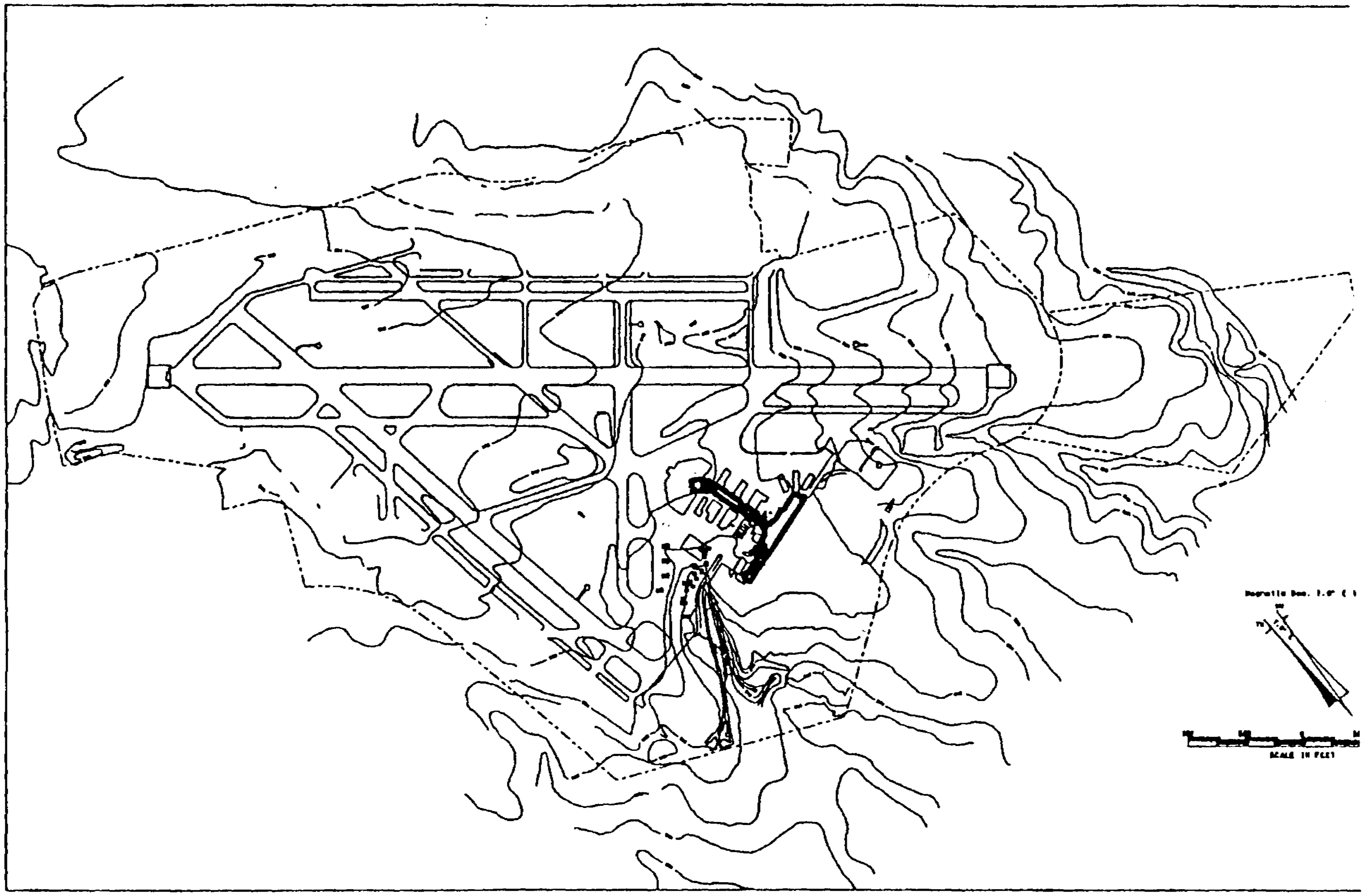

Figure 5.1 Robert Mueller Airport Contours

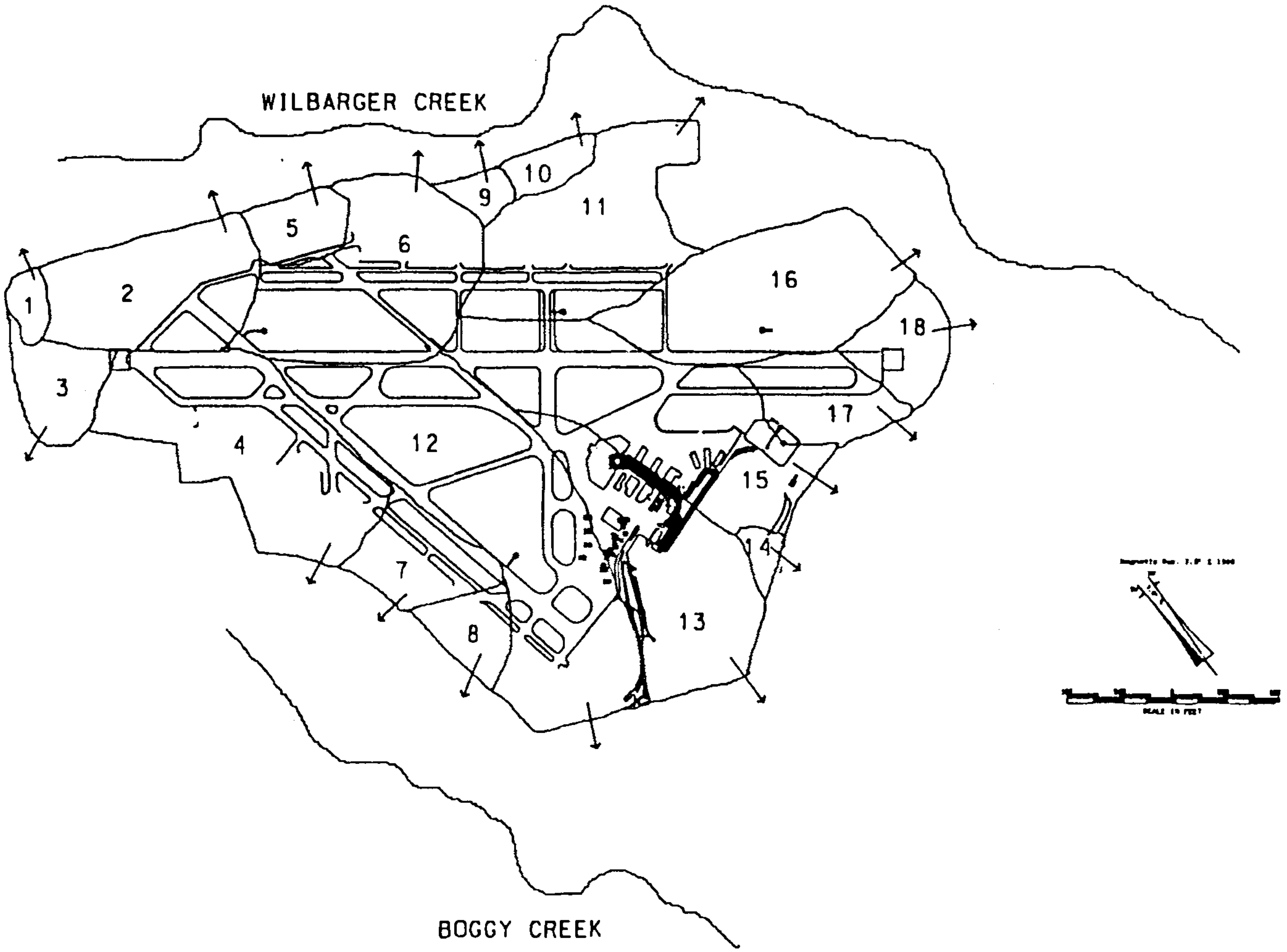

Figure 5.2 Robert Mueller Airport Watersheds

GIS SPECIFICATIONS FOR SWPPP

It is very difficult to actually propose specifications for a GIS to be used for a SWPPP, since the FAA Advisory circular providing a sample SWPPP has not been released to the public. Also, the requirements may be different, depending upon whether the airport has a general permit, a multi-sector general permit, or an individual permit. Airports that use large amounts of deicing fluid or have runoffs into sensitive waters are more likely to have their SWPPP under greater scrutiny than those that don't. Airports that are under EPA enforcement action also have a higher level of scrutiny. Another compounding problem is that state requirements can be more restrictive in those designated states.

What is provided in the following section for suggested specifications for a GIS to be used for a SWPPP is based upon the following assumptions:

1. General permit,
2. Group application, and
3. Required sampling for deicing fluid.

A GIS for use in compliance with EPA guidelines for a SWPPP should contain the items listed below:

1. The base map should include the following:
   a. Outline drainage areas boundaries within the airport property lines with a horizontal precision of 10 meters. The boundaries should be converted into polygons for spatial analysis.
   b. Identify all storm water outfalls or discharge points from each drainage area with a horizontal precision of 5 meters. The outfall points should be converted to topological features as points.
   c. Show all surface water bodies and named creeks and rivers. The surface waters should be converted into topological features either as polygons or line segments.
   d. Locations where those items listed as significant materials are exposed to precipitation should be identified as points or polygons.
   e. Locations where major leaks/spills of significant materials have occurred should be identified as points. Features should be topologically created and linked to a database which also includes dates of spills.
   f. All structural control measures should be identified on the map and be topologically indexed.
   g. Locations of all high-risk waste-generating activities where such activities are exposed to precipitation must be identified and indexed to the data base.
   h. Areas where tenants have primary responsibility for maintaining best management practices must be highlighted and identified on a separate layer/level for spatial analysis.
   i. All areas of impervious cover must be identified, and the system must be able to calculate the percent impervious cover and coefficient of runoff (if desired) for each subwatershed.
   j. If a drainage master plan has been prepared, the plan will be used as a basemap with necessary features topologically created.
   k. The base map will also include specific reference features such as runways, taxiways, buildings, and other features deemed necessary by the airport.
   l. The GIS will be linked to the attribute database so that, as any watershed is identified by the mouse, the information related to that watershed or subwatershed as to permit designation, watershed characteristics, inspection dates, sampling results, persons responsible for spill response, significant materials inventory, deicing chemical release log, or other items can all be accessed by the GIS.

SUMMARY

The Environmental Protection Agency requires airports to file for either a general permit, multi-sector general permit, or individual permit for storm water discharges from the airport property and all permits will require the preparation of a storm water pollution prevention plan (SWPPP). The airport is also responsible for the actions and training of its tenants with respect to storm water discharges.

AAAE has recently prepared a sample SWPPP which can be used as a model for other airports to use in the preparation and update of individual plans. The FAA is also preparing an advisory circular to provide guidance on SWPPP. The purpose of the SWPPP for airports is to reduce the flow of deicing chemicals or fuel spills into the storm sewer, to eliminate illicit connections to the storm sewer system, and institute best management practices and training to prevent pollution from occurring.

Although a GIS is not necessary to comply with EPA guidelines, all of the required items in a SWPPP can be stored and displayed in a GIS and will permit better visualization of the data that is being managed. A GIS can help managers determine if required inspections and training are being updated.

A description was given of how watershed data was developed for the Robert Mueller demonstration GIS.

Once a GIS has been developed with the watershed data other analyses are possible. The best possible use of the airport GIS for water runoff is in consolidating the requirements of the storm water pollution prevention plan and using the GIS to document and display the compliance with Federal EPA regulations and rulings.

Sample specifications and suggestions of what should be included in a storm water GIS were listed. A GIS for use in compliance with EPA guidelines for a SWPPP should contain all the required items for that particular state and airport. Most of the required items are readily visible on a base map. However, additional requirements such as documentation of inspections can be contained in a relational database. As potential fines and criminal penalties are possible, care should be taken to comply with all EPA requirements.

CHAPTER 6. APPLICATION OF GIS FOR NOISE ANALYSIS, MITIGATION, AND MONITORING

The environmental effect of aircraft noise is one of the major financial issues facing airport engineering and management. The cost — of mitigating aircraft noise to the airlines (and indirectly through higher fares to the traveling public) for the purchase of new quieter aircraft, and of FAA-approved noise mitigation programs at airports — is staggering. According to presentations by the airports, the cost of mitigating the noise at the Minneapolis-St. Paul airport is expected to exceed $250 million dollars over a 5-year period, and in Seattle the cost is expected to be $140 million for a 15-year program.[22] This chapter describes GIS applications and specifications for using GIS for noise analysis, mitigation management, and noise monitoring.

BACKGROUND

Environmental analysis and management of aircraft noise fall under the purview of several federal regulations. The regulation with wide application underlying all environmental analysis is the National Environmental Protection Act (NEPA) of 1969, which was written during the era of the very noisy, first turbojet commercial aircraft. The act requires the preparation and approval of an Environmental Impact Statement (EIS) for all major construction, including that at airports. The FAA developed Federal Aviation Regulations Part 150 that formalizes the measures required at airports to receive federal funding for noise mitigation.

The Airport and Airway Improvement Act of 1990 also specifies, for airlines operating in the US, new requirements for the mix of aircraft between noisy Stage II certified aircraft that must be phased out by 1999 and quieter Stage III certified aircraft. The other major federal initiative affecting aircraft noise analysis is that resulting from the study conducted by the Federal Interagency Committee on Noise (FICON), which continued to endorse the day-night level of sound measurement (Ldn or DNL) as the only approved sound metric for all federal noise mitigation measures.[23]

The results of the above federal regulations and policies affect noise analysis, mitigation, and monitoring at airports by controlling federal funding for noise mitigation programs. Noise mitigation programs can be very costly, and even those with the best of intentions in airport planning can not accurately foresee and economically plan for all eventualities in the future. GIS can be an important tool in analysis, mitigation management, and monitoring programs for aircraft noise. GIS can assist in the visualization of data that represent the geographic areas, properties, and people affected by noise. By understanding the needs of the engineers, planners, and administrators for noise analysis and management, it is possible to see how GIS can be both a useful and a cost-effective tool.

NOISE CALCULATION AND ANALYSIS

The most important step in preparing an Environmental Assessment (EA) or EIS related to airport noise is calculating the 65 and 75 Ldn noise contours. These contours surrounding the airport represent lines of equal intensity of noise disturbance to the community, based upon the yearly average of the 24-hour equivalent noise level weighted with a 10 dbA penalty for night operations. Studies have determined the percentages of residents that will be highly annoyed by noise at each of these contour levels, and the FAA has made policy decisions for noise mitigation based upon these contour levels.[24]

The only FAA-sanctioned methods of calculating the 65 Ldn and 75 Ldn noise contours around airports are those using two calculation models: the FAA Integrated Noise Model(INM)[25] and the US Air Force Noise Map Model. The Noise Map Model was developed by the Air Force for use in determining noise generated by military aircraft using military airfields. The model is similar in how it calculates a noise contour but is intended for use primarily by the military and does not have the civilian aircraft calculation curves necessary for computing noise contours at civilian and joint-use airfields.

The calculation of noise contours is very complex, and each individual takeoff or landing can produce a certain noise level based upon many factors. Some of the factors which affect the noise level and for which the INM does take into account include the following:

1. The flight track of the arriving and departing aircraft;
2. The flight profile (height, configuration, and power settings) of arriving and departing aircraft;
3. The aircraft type and characteristics, which include:
   a. The exact aircraft type;
   b. The weight of the aircraft (quantified by the distance to destination of departing aircraft);
   c. The exact type and manufacturer of the engines; and
   d. The certificated noise level of the aircraft (stage II or stage III);
4. The time of arrival and departure; and
5. The yearly average of wind direction or the percentages for landing directions.

An additional complication in computing the noise contour is that the noise measurement scale is logarithmic. A 3 dB increase in sound pressure level is essentially a 100 percent increase in pressure level. Two simultaneous 100 dB sounds produce a 103 dB sound level. A 100 dB sound and a simultaneous 80 dB sound produce only the 100 dB sound level.[26]

Another complication in computing the noise contour is that Ldn is based upon average time exposure or equivalent sound pressure level (Leq). The single-event noise levels of jets at takeoff are often over 100 dB measured on the commonly used A weighted scale. The A weighted scale takes into account the sound sensitivity of the human ear by decreasing the levels of low-frequency sounds and increasing the sound level for high-frequency sounds. There is a special D weighting scale that was developed to measure jet aircraft noise with an additional penalty for the high-pitched frequency of jet noise, but it is not used for calculating Ldn.

Rather than basing community response on the single-event noise level, it is the aggregated noise levels that are measured. For instance, a single 100 dbA noise event averaged with several hours of typical 65 dbA heavy urban traffic may produce a Ldn level of near 65 Ldn, while several 100 dbA events totaling over 15 minutes averaged with several hours of 65 dbA may produce a 75 Ldn noise level. The EPA has determined from research studies that at the 65 Ldn level, 20 to 40 percent of the residents will be highly annoyed, while at the 75 Ldn level, a majority of the residents will be highly annoyed.[27] The Ldn metric is also used by the Department of Housing and Urban Development and by the Veterans Administration for guaranteeing mortgages based upon proximity to all types of noise sources.

Obviously, computing the exact locations of the officially approved FAA 65 and 75 Ldn noise contours around airports is not something that can be done without a complicated model. In fact, the FAA requires that the documentation be submitted with the noise contours to approve the contours and the noise mitigation plan.

If an airport expects to receive FAA funding for noise mitigation or FAA approval for any construction requiring an Environmental Assessment or EIS, the only approved method of calculating the noise contours is to use the FAA Integrated Noise Model. Current EIS guidelines require that a noise contour map be prepared at a specific scale to overlay existing maps. The latest version of the INM, version 4.11, is an IBM-compatible, PC-based microcomputer version that requires many input variables to achieve the output contour.[28] The input variables are constantly changing at each airport, and 5-year forecasts are required. The engineer or planner who analyzes the noise contours must understand all the operational variables, FAA and airport flight restrictions, and airline and pilot noise abatement procedures.

Airport and FAA decision makers and the airlines can make choices in operating procedures that affect noise contours, which in turn can determine the costs of noise mitigation as well as the number of persons adversely affected by noise. However, the INM is so difficult, time-consuming, and costly to prepare for each alternative that most airports hire a consultant and calculate noise contours specifically only for an EIS or a master plan update.

Ideally, some airports have said that they would like to have new noise contours prepared quarterly. One reason is that, without knowing the resulting effects on the noise contours, decision makers must either estimate or make decisions on changes to airport and airline operations without that information. Another reason is that, if contours change more than 1.5 Ldn, re-negotiation of special land use agreements called avigation easements will be required.

It is possible, using a GIS, to integrate the information that is necessary to calculate and analyze the noise contours. This process includes the following:

1. Build an INM input file using the decision makers alternative choices.
2. Run the INM model.

3. Plot the noise contours.
4. Use the spatial analysis capabilities of the GIS, to determine the effects of alternative operational choices upon each dwelling surrounding the airport.
5. Show the results graphically so that administrators and non-technical decision makers can readily understand the consequences of alternative operating procedures.

EXAMPLE GIS FOR INM INTEGRATION

To demonstrate the feasibility of this concept, the following example has been prepared. The noise contours were calculated for two examples using the chronological data file supplied on diskette by the Official Airline Guide (OAG) for Dallas/Fort Worth International Airport (DFW) for March 1994. With simple sorting techniques, the weekly flight schedule current as of March 1, 1994. was compiled. INM database aircraft types, which are based upon noise characteristics, were translated for OAG aircraft codes that are based upon passenger and cargo capacity. Aircraft destinations were used to calculate the length of each flight and summarized by aircraft type and stage lengths (flight length categories 1-7). Flight departure and arrival times were used to assign each flight to the day (0700 - 1900), evening (1900 - 2200), and night (2200 - 0700) categories. The distribution of average daily flights by hour is shown in Figure 6.1. Runway layouts, including two new runways approved for construction, and their associated arrival and departure tracks, were described in INM format using a local coordinate center corresponding to actual geographic coordinates.

For the example problems, using statistical analysis software programs, the scheduled flights as of March 1, 1994, for DFW by aircraft type, stage length, and time of day category were summarized; a complete list by INM aircraft database is provided in Appendix C. The flights were then mathematically distributed by the following methodology for Example 1:

1. Wind conditions were assumed to be 70 percent south wind and 30 percent north wind. (Aircraft would take off and land on Runway 18R 70 percent of the time, and take off and land on the opposite end of the same runway, Runway 36L, the other 30 percent, because of seasonal wind patterns or operational decisions).
2. The shorter diagonal runways (13R/31L and 13L/31R) were not allocated any wide-bodied aircraft (B747, L1011, DC10, and MD11) because of problems with insufficient runway length for takeoff.
3. Runway 16-34 East was hypothetically assumed to be fully operational all year, and Runway 16-34 West was assumed not to be operational all year.
4. All flight tracks were simplified to straight arrivals and departures. (Actual flight paths will change the actual contour shapes, but this simplification is used for the comparison of the two examples.)
5. Distribution of traffic was assigned at 18 percent each to the 5 north-south runways and 5 percent each to the 2 shorter diagonal runways.

Using the above assumptions, the INM version 4.11 was run on an IBM-compatible 80486/33 MHz desktop computer, requiring over 3 hours to calculate the 65 Ldn and 75 Ldn contours. The analysis determined that the area within the 65 Ldn contour is 43.29 square miles for Example 1.

However, to illustrate the analytical capability, an operational question was posed. What if, to reduce tower personnel, the soon-to-be-built Runway 16-34 East was assumed to be closed for all departures from 7:00 p.m. to 7:00 a.m. and, because of the long taxi time, all day time scheduled turboprop and commuter-type aircraft previously assumed to depart from that runway were split evenly among the remaining four north-south runways.

Noise contours were calculated for Example 2 using this operational change to the runway assignment of aircraft departures. The total number and type of aircraft were the same, and the other four assumptions regarding wind conditions, flight tracks, and other runway assignments remained the same. The analysis of the second example indicates that the area within the 65 Ldn contour has shrunk to 40.60 square miles. Therefore, this potential change in operational procedures resulted in a 2.69-square-mile decrease of area within the 65 Ldn noise contour, which appears to be mostly in the off-airport properties. Figure 6.2 shows both DFW contours with the second example 65 Ldn contour represented in bold.

It is feasible to convert these alternative noise contours into GIS noise polygons for spatial analysis in several GIS software platforms. If the base map of the GIS has topological data of the locations of the off-airport properties and attribute data of the residents and their mailing addresses, it would be a simple matter to have the GIS determine which properties were affected by this alternative and print out mailing lists. Without GIS tools, it would not be possible to quickly determine the noise effect of any given choice of operational alternatives.

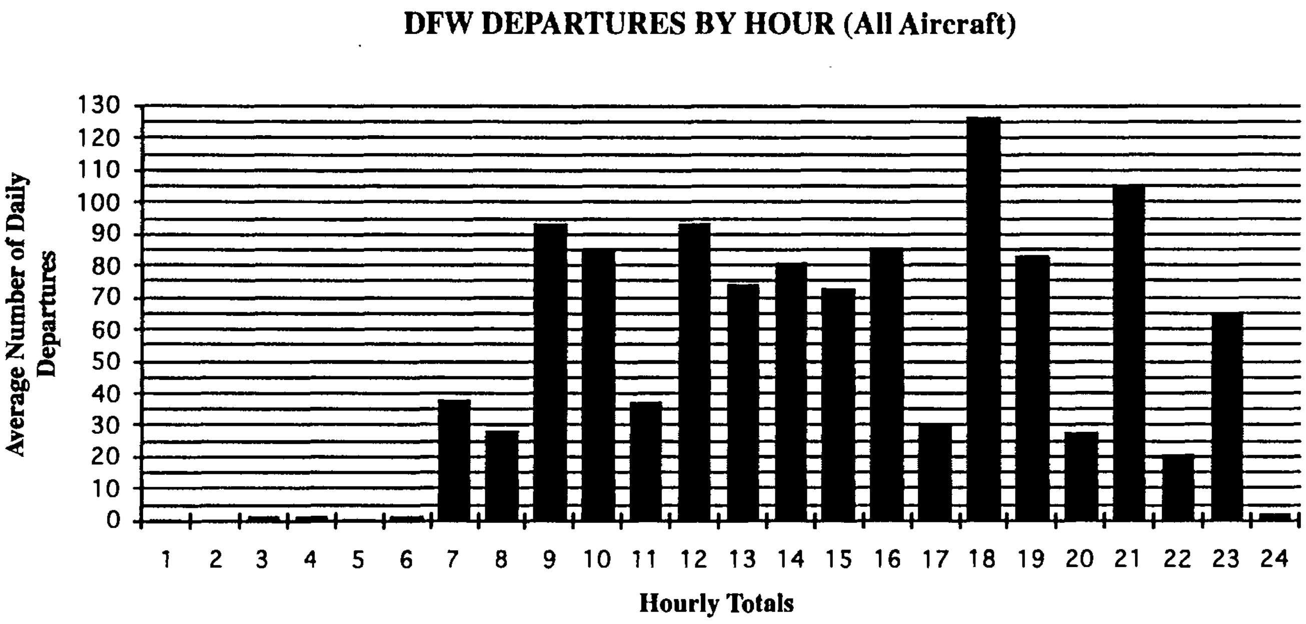

Figure 6.1 Distribution of DFW Departures by Hour

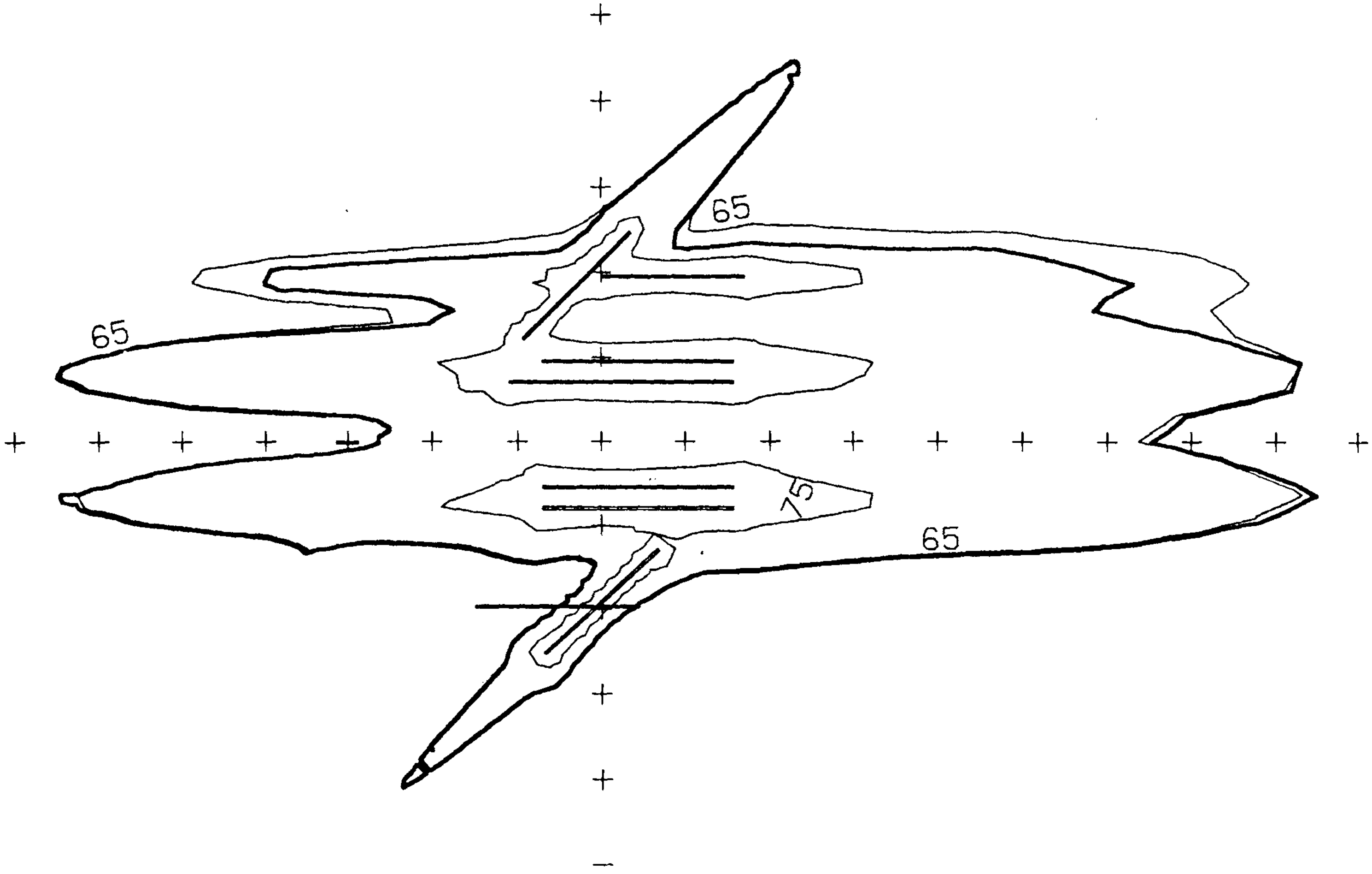

Figure 6.2 DFW Noise Contours Using OAG Data for March 1, 1994 (Example 2 in bold)

This is one of many possible examples of how an INM might be integrated with a GIS at the airport to analyze operational decisions and their impact upon the surrounding community. Other potential "what if" questions that might be asked of the airport authority include:

- What is the impact of adding a number of new flights to the schedule?
- What is the impact of adding a new aircraft type to the schedule?
- What potential savings in mitigation costs could be achieved by alternative flight paths or takeoff and arrival profiles?
- What is the added effect of allowing additional touch-and-go practice approaches?
- What is the effect if a runway is taken out of service for long term reconstruction?

GIS SPECIFICATIONS FOR INM INTEGRATION

Currently, the limitations in integrating the FAA INM version 4.11 with a GIS do not lie with the GIS, but are rather a limitation of the INM itself. It is possible to manually perform this integration by taking the output files of the INM and manually converting the data into a form that can be plotted in a CAD file or a Windows file. INM version 4.11 is a FORTRAN file format program, and the output files cannot be used directly to input into any existing CAD or GIS program directly without manual file manipulation or custom programming. There is a shareware program available to convert the INM contour file into CAD programs via the DXF file format transfer utility. However, INM version 5 is a Windows-based program that the FAA has promised to release before the end of 1994 and has been specifically designed to permit compatibility with GIS software. The INM Version 5 will support the export of contours to CAD and GIS formats. It may support import of flight tracks from CAD drawings. Version 5 is eventually expected to be released in Windows 3.1, Windows NT, and UNIX workstation compatible formats.

The following specifications for customized GIS software are suggested if full integration with the INM version 5 is planned:

1. The customized GIS must be capable of importing the graphic INM noise contour files of INM version 5 on an IBM compatible microcomputer by the desired method (through a network, seamless operation on the same platform, or diskette) and use the files to construct noise contour polygons, geographically oriented, and be able to spatially analyze what lies within or outside the noise contour polygons.
2. Software will be provided for the INM input for making alternative choices based upon the following parameters:
   a. The software will support changes in the input of the flight schedule based upon the mathematical derivations of electronic copies of the Official Airline Guide.
   b. The software will support changes in the input of the geometry of arrival and departure flight tracks in a specified CAD program.
   c. The software will support changes in mathematical assignment of aircraft to runways and flight tracks based upon characteristics of the aircraft type, aircraft destination or point of departure, airline, instrument approaches, wind conditions, time of day, takeoff and arrival profiles, and other user-specified assignment routines.
3. The software will provide the user with a save capability such that easy changes are made from one alternative to the next and that identification of the alternatives can readily be made.
4. The software must have the ability to lock data and noise contours such that people without proper access can view only existing certified or alternative contours but cannot modify data or contours.

MANAGEMENT OF NOISE ABATEMENT

Noise is an unavoidable product of airports with jet traffic. There are three separate and distinct activities that can take place at airports concerning noise:

1. Noise reduction,
2. Noise mitigation, and
3. Noise management.

Noise reduction consists of the steps undertaken to actually reduce the amount of noise, such as changes to operating hours, pilot noise abatement procedures, construction of hush houses for muffling engine maintenance runs, and changes to the aircraft. *Noise mitigation* includes steps undertaken to mitigate the effects of noise on the airport users and residents in the surrounding communities. *Noise management* would be considered the steps undertaken to improve community relations, improve the perceptions of noise, or reduce the frustration of the community in coping with the noise. But often the steps do not directly reduce or mitigate the noise itself. Examples of noise management include noise monitoring programs, noise reporting hotlines, and active community involvement groups.

FAA Part 150 Program

The FAA has instituted a voluntary Part 150 program in which the FAA contributes funding for noise mitigation and some noise management programs. For airports to participate, an approved Part 150 study must be performed and a noise mitigation program must be submitted for approval. Only those items approved in the noise mitigation or management program will be approved for federal funding.

Basically, the FAA supports several options for mitigating the effects of noise in the surrounding community. The first option is outright purchase, in which the airport purchases the affected property and demolishes structures that would constitute incompatible land use. This option is usually exercised only for residences inside the 75 Ldn noise contour.

Another well known option is to sound insulate the dwellings to reduce the effects of noise. This can be a costly option, and the average price to sound insulate a home in the $250 million noise mitigation program at Minneapolis-St. Paul Airport is nearly $40,000. Problems arise with sound insulation related to how much insulation can be achieved at what price and whether the cost of the insulation is greater than the cost of the dwelling. The greater the noise reduction required, the more drastic the measures required and the higher the costs to achieve the reduction.

Two other less well known noise mitigation programs that also qualify for federal funding are purchase assurance and avigation easements. In purchase assurance, since the effects of increased aircraft noise have the possible effect of reducing the value of the dwelling and surrounding property, to alleviate apprehension of this perceived loss of property value, the airport agrees that if the buyer cannot sell the property at what fair market value would normally be, the airport will guarantee to pay the difference to the property owner at the time of sale.

The remaining noise mitigation measure eligible for federal funding is the "avigation easement." This is the legal term applied where the airport agrees to pay the property owner a small remuneration for the right for aircraft to make a certain level of noise as measured in the Ldn noise contour. The is not the same as overflight rights which airports and aircraft already have. The avigation easement must be renegotiated if that noise level is exceeded by 1.5 Ldn.

Management of Noise Mitigation Programs

The management of a noise mitigation program can be a significant project in itself. The noise mitigation for adding two new runways at Dallas/Fort Worth International Airport is expected to affect over 5,000 properties. The cost of acquiring the property and constructing the east runway is estimated at approximately $190 million. The cost of mitigating the noise for the east runway is nearly equal to the construction cost and is estimated at $177 million, involving over 2,300 properties over a 5 year period.[29]

Managing 5,000 properties and trying to explain the options available to the homeowners can be a daunting task, even with a good management system. It requires a system that utilizes project management for scheduling the insulation or other mitigation project at each dwelling, and it combines elements of infrastructure management for maintaining the inventory of what has been accomplished. And, most importantly, each dwelling or property must be related geographically to the airport and noise contours. In the case in which a property owner elects an avigation easement, the actual noise contours must be analyzed with respect to forecast noise contours to monitor and maintain compliance with the easement.

Geographical information systems are a very useful tool for management of noise mitigation programs. GIS is designed to integrate the large amounts of attribute database information and visually display the information such that an engineering degree is not required for the user to understand it. It becomes a valuable engineering tool to locate each dwelling and its geographical relationship to the airport and noise contours. It also is a management tool for keeping track of mountains of information and for displaying measurable progress. It also serves as a public interface tool for showing the homeowners graphically the effects of the airport noise upon their own and their surrounding neighbors' homes.

GIS SPECIFICATIONS FOR MANAGEMENT OF NOISE MITIGATION

The following specifications are suggested for customizing a GIS for management of a noise mitigation program:

1. The Base Map must be developed with property boundaries with a horizontal positional accuracy of 10 meters.

2. The Base Map must be developed with dwelling locations as topological features with a horizontal positional accuracy of 10 meters, and with each structure or vacant property having a separate postal address matched to an attribute database with complete postal address.
3. The Base Map must be geographically referenced to the airport and existing noise contours with a horizontal positional accuracy of 5 meters.

The following guidelines are suggested for customizing a GIS for management of a noise mitigation program:

1. Data should be password-protected and should reside in a safe secure location. A backup data storage system should be required.
2. The GIS should interface with any other noise applications such as the INM model and a noise monitoring system.
3. The management system should provide adequate information for managers to manage the program and provide graphic outputs suitable to convey information to residents and decision makers.

NOISE MONITORING APPLICATIONS

Many commercial service airports have elected to adopt noise monitoring systems as part of their overall Part 150 noise compatibility programs. The current policy is that the FAA will not require an airport to establish a noise monitoring program; but, if the airport elects to add noise monitoring as part of the system of noise management in its Part 150 noise compatibility program, it would be eligible for federal participation in funding.

Noise monitoring has been used for a long time at airports, and the first use was probably that of enforcement of pilot noise abatement procedures. The simplest use is to install a microphone at a distance off the departure end of the runway and levy fines based upon the amount of noise produced for each flight. This practice is highly discouraged by the FAA and by pilots, because it leads to pilots having to try to "beat the box."

Anecdotal evidence suggests that, at one time at a New York airport, Pan American Airlines had ground personnel positioned near the microphone with a radio, so that the pilots could be instructed as to the best time to reduce power and glide past the box. Pan American even attempted to sell this service to other airlines to help recover the costs. More recently, at John Wayne Airport in Orange County, California, airline pilots were instructed by their airlines to perform a similar power reduction during takeoff at altitudes much less than, the generally accepted, 1,000 feet above field elevation (AFE). After lengthy study of the John Wayne Airport procedures, the FAA has established a safety standard where none previously existed to prevent pilots from making the noise abatement power reduction below 800 feet AFE.[30]

The more normal use of noise monitoring at airports is to attempt to determine which aircraft are not correctly following approved noise abatement procedures. The National Business Aircraft Association (NBAA) publishes every other year a consolidated list of the airports which have noise abatement procedures and a short summary of each. The 1993 Airport Noise Summary lists 596 airports with some form of noise advisory or control.[31] The noise abatement procedures range from voluntary restrictions of jet operating hours to mandatory specific departure routes, altitudes, and single-event noise limits.

The more sophisticated noise monitoring systems use the radar track of the subject aircraft and match the identification to determine which aircraft are exceeding the limits at which microphones and at what time and over what time duration. In the case of Tetterborough Airport in New Jersey, for each over-limit noise incident, each pilot is sent a letter indicating that his aircraft did not comply with the noise abatement procedures or did not meet the noise reduction limits set by the airport. This noise monitoring program is used to get pilots to comply voluntarily with noise limits and has worked rather successfully.

Many airports have a noise abatement office in which the duties usually include management of a noise monitoring system, receiving and investigating noise complaints from the public, and monitoring compliance with noise abatement procedures. The nation's most active noise abatement office is probably at Minneapolis-St. Paul (MSP) Airport, where over 500 noise complaints are received per month. In fact, the airport employs five telephone operators to process all the noise complaints.

At MSP, a noise monitoring system was purchased under the airport's Part 150 noise compatibility program with the expressed purpose of linking the radar tracks of aircraft and noise events of microphones. A GIS is under development to help manage all the noise complaints and also to display the map of the flight tracks and noise events. The desired goal was to allow each operator receiving a noise complaint to use the GIS to look up and compare the time of complaint, location of complaint, noise events of the closest microphones, and radar tracks of actual aircraft. Computer analysis in near real time could allow the operator, while talking to the person making the noise complaint, to have a computer projection at the caller's location of the estimated single-event noise level of the event that precipitated the call.

From experience at MSP, not all the noise complaints were precipitated by aircraft flying into or out of MSP. Some complaints may be linked to other aircraft flying over the area or to other aircraft flying out of nearby airports. Experience at MSP also showed that some complaints seem to be from habitual callers at noise event levels well below usual noise levels that would normally cause complaints. Even with a few unwarranted complaints, the strong public involvement of the citizen groups is considered a very positive influence at MSP. The GIS and noise management system are considered essential ingredients of the public relations efforts at MSP.

What a combined GIS and noise monitoring program at MSP does best, is to take the emotional issue of environmental degradation by aircraft noise and graphically display the scientific facts in a manner that is easier to understand. After the emotions are calmed down, discussions and education take place and realistic expectations can result. Public involvement in the Part 150 noise compatibility program is required, but efforts that go beyond the one required public hearing have paid big dividends at many airports.

GIS SPECIFICATIONS FOR INTERFACE WITH NOISE MONITORING

How to specify how a GIS would be interfaced with a noise monitoring system is somewhat difficult if a competitive procurement is required. In the case of DFW airport, the procurement was for a noise monitoring system, and the GIS was considered to be an added deliverable. This is not necessarily the best method, because the competitive noise monitoring proposals should be considered separately from the GIS. However, if it is desired to have a single vendor deliver both, it appears to be a workable solution. There can be some synergism in building a GIS with a monitoring system, since the noise monitoring vendors need a map for their output whether a GIS is present or not.

The problem arises because noise monitoring is probably not the only user of the GIS; the software and hardware may already be dictated by other requirements. Large noise monitoring systems often cost several million dollars to develop. A large multi-user GIS can also cost over a million dollars, but if the base maps are already drawn for some other application, the cost can be considerably reduced. It has been estimated that the hardware and software requirements of a fully functional GIS are only 10 percent of the cost of implementation. The cost of building the base map and collecting data are by far the largest costs - many have estimated that these two steps comprise 80 percent of the cost.

The best advice for developing a specification for a GIS to be used in conjunction with a noise monitoring system is to be as specific as possible in explaining what is really wanted.

1. Specify the hardware platforms and the methods of data interface.
2. Specify the GIS software to be used and the attribute database software to be used.
3. Specify what is to be displayed in which locations.
4. Specify what data are already available and the accuracy, lineage, condition, and documentation of the data.
5. Specify who the users of the system are to be.
6. Specify what spatial analysis, if any, will be performed on the data.
7. Try to predict what capabilities may be needed in the GIS for spatial analysis in the future.

The following is a synopsis of GIS specifications prepared by Dallas/Fort Worth International Airport for a noise monitoring proposal which included a request for a map overlay system/GIS:[32]

1. Integrate with flight tracking system and import INM plot files. Rapid intersection of layers for spatial analysis.
2. Provide hardware and software compatible with existing Intergraph MGE/MGA GIS software and Oracle database.
3. Provide the following GIS layers
    a. Regional road network.
    b. Detailed road network, streams, communities, political boundaries, parks, and other major public lands.
    c. Proposed highways.
    d. Census block and tract boundaries with population data, household counts and characteristics.
    e. Zoning (past, present).
    f. Land use (past, present).
    g. Community facilities.
    h. Noise monitoring stations, noise contours.

4. Data to locate land parcels and their ownership and characteristics.
5. Software flexibility for developing new layers and display for rapidly adding or subtracting selected layers.

6. Display and locate by address or specific feature. Track building permits, variances, easements, and complaints over time.
7. A digitizing tablet for the computer system.

SUMMARY

The day night level (Ldn or DNL) is the approved sound metric for all federal noise mitigation measures and the FAA Integrated Noise Model (INM) is the approved method of calculating noise contours at airports. Noise mitigation programs are very costly and airports generally rely on federal funding for Part 150 noise mitigation programs.

GIS can be an important tool for engineers, planners, and administrators for analysis, mitigation management and monitoring programs for aircraft noise. Integration of INM with GIS will be more easily accomplished with the future release of INM Version 5. The engineer or planner who analyzes the noise contours must understand all the operational variables, FAA and airport flight restrictions, and airline and pilot noise abatement procedures. Proper analyses permit airport and FAA decision makers and the airlines to make choices about operating procedures that can affect noise contours. Thus determining the costs of noise mitigation as well as the number of persons adversely affected by noise. Integration of INM with GIS permits the airports to understand the consequences of alternative operating procedures by performing comparative cost benefit analyses.

A demonstration was performed using OAG scheduled flight data for DFW Airport and calculating the comparative noise contours for two operating scenarios. The example showed a 3 square mile reduction in the area of the 65 Ldn noise contour by restricting take-offs at evenings and nights from the runway currently under construction. The noise contours can be converted into topological features and analysis can be made of the number and addresses of dwelling within the comparative contours.

Suggested specifications for GIS software for full integration with the INM Version 5 include the ability to spatially analyze what lies within or outside the noise contour polygons, manipulate the OAG flight schedule, and change the geometry of flight tracks with CAD. Suggested specifications for GIS for management of a noise mitigation program should include an accurate base map with dwelling locations as topological features matched to an attribute database with complete postal address.

Noise monitoring is becoming more common at busier airports and can be funded in the Part 150 noise management program. The more sophisticated noise monitoring systems can use GIS to display the radar track of the subject aircraft, match the aircraft to a noise event at a microphone, and geographically match complaint calls to noise events.

What a combined GIS and noise monitoring program does best is to reduce the emotions of the issue and allow discussion and education to take place with the required public involvement. GIS specifications with a noise monitoring system should include the hardware requirements, the GIS and attribute software, what is to be displayed, the users of the system, and what spatial analysis will be performed on the data.

CHAPTER 7. APPLICATION OF GIS FOR MANAGEMENT OF AIRPORT PROJECTS

Airports are perpetually changing as projects are underway to accommodate growth in passenger and cargo facilities, changes in airlines and airline service, and needs for rehabilitation or maintenance. Most of the projects are contracted and managed by the airport, with some maintenance performed by airport staff. However, the issue of security at airports, the potential for disruption to aircraft and passengers, and the requirements for advance coordination and scheduling make for a hectic-paced management problem.

Air carrier runways, based upon current construction costs, are approximately a $150,000,000 dollar resource. Capacity is a critical national resource to the air transportation system, and spare runways at air carrier airports are not kept on hand for the times when maintenance and rehabilitation are required. Airport Improvement Projects (AIP) are usually planned with a minimum of disruption time to the runways; often construction is limited to nighttime hours only. Safety dictates that no stockpiles of materials be left around the runway, cleanup be accomplished each night, and the runway be swept and inspected in time for early-morning departures and arrivals.

Planning and communications are essential for good construction projects at active airports. Each project needs a map of the areas to be used. When multiple projects are being undertaken or multiple contractors and subcontractors are involved, the communication and coordination must be even better. A map-based coordination and project scheduling system could prove valuable.

Project management or scheduling software has been used for quite some time now. It is likely that very few if any major construction projects are managed today without some computerized management software. What a GIS could do is to add map-based graphics to the project management system. Scheduling of projects for specific areas can be integrated with a GIS. As schedules change, the GIS can point out potential space or routing conflicts. As items are completed or as milestones are reached, the GIS can trigger necessary coordination or management actions, such as preparing the Notice to Airmen (NOTAM) that must be given before runways, taxiways, or navigation aids are taken out of service or unusual activity is planned that might divert or require pilots' attention.

In the write-in space provided in the survey of airports discussed in Chapter 2, several responses indicated management of projects or work on projects. Those listed included:

Planning Development/ Project Applications,
Tracking Construction and Design Progress,
Automated Work Clearance Requests, and
Interface With Work Information Management.

Together, these responses indicate a preference for a management system that is accessed by the airport operations division, accessed by engineering and worker forces, and probably accessed by contractor work forces. It should be a graphic system permitting the use of CAD drawings; it should show the location of work areas related to the airport and safety zones; and it should integrate graphics with attribute databases. It appears that what is needed is a system that either SmartCAD or a GIS can perform. It may not be necessary for a project management system to have a spatial analysis component, unless it also is necessary for the system to be used for analysis in the design phase of the project.

It may be hard to justify the cost versus the benefit for developing a GIS solely for use as a project management software tool. However, if space management is a requirement and there are other departments that need data from the project management system, it may be beneficial. If a GIS is already under development or in the planning stages, adding the ability to manage projects or integrating project CAD data with some management routines may be inexpensive.

If management of projects at the airport is a potential application for a GIS at the airport, the following guidelines are suggested:

1. Use is recommended of a GIS that has a CAD-based graphic engine or can manage CAD drawings. Some GIS packages can access CAD-based drawing tools. If the GIS selected does not have that capability, it probably will not provide enough information for the task.
2. The GIS must have multi-user network capability.
3. The GIS must permit full access to authorized users but only limited access to those who should not have authority to change the data.
4. It is recommended that specialized software be added or purchased to enhance the productivity for project management.

CHAPTER 8. APPLICATION OF GIS FOR AIRPORT TERMINAL MODELLING

The development of computer simulation and modelling programs, such as the FAA SIMMOD program, have increased the design and analysis awareness for airport terminals. Since graphics conveys so much more information per unit of time, it is necessary for simulation modelling. Since the graphic capabilities of GIS are so well developed it follows that GIS might be able to integrate airport terminal modelling programs. This chapter investigates the capability versus need at airports.

DO AIRPORTS NEED TO PERFORM SIMULATION MODELLING?

In major airports, modelling of the airport terminal can be very important. New state-of-the-art terminals are often modelled to test the operating efficiency, the geometric layout, and the estimated level of service for sizing the different components and systems of the terminal building and interfaces.

In existing airports, the first question becomes, is a modelling program that is used to simulate passenger flows necessary for this airport? It is proposed that only a select few existing airports actually require this capability. Even if the capability *is* required for planning for a reconstruction in the terminal, the modelling of the terminal will probably be turned over completely to a consultant. Since this special field of consulting has a limited number of firms and several models to choose from, it not suggested that most airports will find it necessary to perform modelling — and, if they do, they may not have the time or inclination to integrate it with a GIS.

However, GIS is a very flexible system and can accommodate many different applications. In the event that an airport may consider GIS for the application of terminal modelling, the following chapter describes how airport terminal modelling might be integrated with a GIS and what synergism might result.

AIRPORT TERMINAL SIMULATION MODELLING

Airport passenger terminals have been the focus of much study in design and analysis. This intensive study has been due both to the high cost of the structure which has been estimated at over $200 per square foot of space[33] and to the desire to serve the traveling public in an efficient manner. Approval by FAA and limited funding of some research by FAA has led to the development of several airport models that are used in design to reduce the risk of major mistakes and reduce the cost of building airport passenger terminals.

Unfortunately, much of the study was done many years ago. The two best-known models funded by FAA for terminal design ACAP and ALSIM are old models designed in the era of mainframe computers.[34] With the significant recent advances in desktop computing power, much of the current state-of-the-art airport terminal models are being developed by airport engineering consultants for internal use. These proprietary models developed by the airport consultants are usually developed for specific airport projects but are not transferred to the public domain.

The TAM model from Australia is one of more popular proprietary airport terminal simulation models available. The current usage of the ACAP and ALSIM computer models is very limited. SIMMOD is an airport modelling program developed for the FAA and is used primarily for airside and airspace simulation modelling. SIMMOD also models aircraft on the ground, but ends as aircraft arrive at the gate.

COMPONENTS OF AIRPORT TERMINALS

Airport passenger terminals are comprised of several major components. Depending on the size of the airport, some of these components may be consolidated.

However, for airports with scheduled airline service, the minimum components are a ticket office, usually a baggage check and handling component, a security screening facility, a holding facility where screened passengers can wait until boarding, and a gate where the aircraft is parked.

In medium and large airports which routinely handle jet aircraft, the terminal buildings are very complex systems which require design analysis and modelling. The large investment in cost justifies and requires some type of modelling. Odoni pointed out that a very large airport in Italy was found to be inadequate immediately after opening, necessitating millions of dollars in additional modifications to the brand-new terminal building to make it fully functional.[35]

Denver International Airport will cost $3.2 billion dollars to construct[36]. The terminal building is of unique design with a fabric-covered roof as a bold architectural statement. The main terminal building is connected to three concourses so widely spaced that they were designed to be reached only by underground subway cars. A change in design requested by Continental Airlines will permit the A Concourse to be reached by a long passenger corridor bridge over the active taxiway. The cost of the baggage handling system alone for the terminal system is estimated at 20 percent of the construction cost of the airport. Airport terminals are becoming quite complex and quite expensive and are therefore one of the most expensive components of an airport.

AIRPORT TRAVEL DEMAND

There are many different studies and fact and figures available about the future of air travel demand in the United States. Some claim that the industry has matured and will reach a period of stable growth. Others claim that it has not yet matured and can still expect periods of rapid growth depending on the economy of the United States. A few people claim that the proliferation of teleconferencing will result in a significant loss of business travel. Regardless of which study one reads, the common conclusion is that the numbers of enplanements will continue to increase.

According to the Federal Aviation Administration Strategic Plan, the passenger demand at our nation's airports has increased 65 percent in the decade since deregulation.[37] The FAA also expects that the current number of enplanements in the US will double by the year 2010 to over a billion per year. This is equivalent to four enplanements per year for every person in the US.

One of the problems that this increase in demand will create is the problem of capacity and delay at our nation's busiest airports. There are over 500 commercial service airports in the US, but the 10 busiest serve 40 percent of the nation's enplanements. The FAA expects Chicago and Atlanta each to experience over 100,000 hours of delay in 1997. The FAA also expects 33 major airports each to experience over 20,000 hours of delay in 1997.

NEED FOR MODELLING OF AIRPORT TERMINALS

Modelling of airport terminals will become increasingly more important in the future as passenger traffic continues to grow. It seems that airport passenger terminals are never really completed, but rather continue in a state of planning or design for the next needed expansion. The FAA has forecast that the numbers of air passengers in the US will double from current levels in only 10 to 15 years. Flexibility for expansion is a critical need of airport passenger terminals.

There has been an ever-increasing need to improve the capacity at our nation's airports; runways are one important capacity restraint, but airport passenger terminals are another. The capacity of individual components of the airport can control the capacity of the airport and impact the entire system's capacity. At several major hub airports, gate capacity is becoming critical from both the landside and the airside portions of the air travel system. There is also competition from competing modes of travel. The airlines are very interested in keeping the cost of air service down and in minimizing the delay time in a trip at each airport. Therefore the goal of airlines and airports alike is to minimize cost and delay while providing a safe and comfortable environment for the passenger.

This goal has resulted in several attempts to quantify delay and level of service. The largest delay cost to the air transportation system is the airplane ground congestion delay at major capacity restrained airports. Therefore, the current FAA criterion for measuring delay is the delay time from push back to the gate until takeoff, which is considerable and costly.

However, from the perspective of modal system performance, the time it takes from arrival at the airport entrance until departure from the terminal at the final destination airport is all part of travel time, which the traveler wants to minimize. Minimizing the time in the terminal can be one factor in determining the level of service of the terminal. Other factors can be safety and security, pleasantness of the surroundings, level of congestion of the space, and the passenger's ability to determine direction in the terminal. Obviously, a terminal which is makes it difficult to find one's way, and has long lines to process through the terminal, is not providing the same level of service to the passenger or to the air transportation system as the terminal building in which it is inherently easy to find one's way and which causes no long delays in processing.

The researcher would like to include as part of level of service the perceived time that the business traveler feels necessary to arrive at the airport in order to feel comfortable in making his flight. Anything that can be done to shorten that time (real or perceived) such as reduced processing times, short queues, convenient parking, and accurate updates of flight schedules and weather delays could be considered beneficial improvements in level of service of the terminal. In large airports, if each passenger spends less time in the terminal, then there would be fewer numbers of passengers in the terminal at peak times, which could reduce the capacity problems. If every passenger could arrive 15 minutes or less before the flight, there could be one-fourth as many departing passengers in the terminal as there are when they start arriving one hour before the flight. However, this goal could conflict with the goal of generating revenue from concessions at the airport.

Whatever the motivation, there is a documented need to model airport terminal operations to minimize construction and operation costs and minimize the delays and processing times of passengers. Whichever way level of service is defined, there is a need for modelling and simulation to measure the ability of the airport terminal to perform its function.

REVIEW OF THE LITERATURE

There has been extensive literature on the general subject of modelling and simulation of airport terminals, but none that successfully describes integration with a GIS. This discussion will be limited to the simulation of passenger flows throughout the airport terminal and how that can be served by using computer-aided design and drafting (CAD) and/or geographical information systems (GIS). The hypothesis presented is how the physical attributes of space of the terminal influence the level of service and how simulations which take these physical dimensions into account are good candidates for GIS and/or "smart CAD." Therefore, only those items in the literature which directly relate to the modelling and simulation of the passenger flow are discussed.

At the Workshop on Future Airport Passenger Terminals, sponsored by the Building Research Board, the participants noted that 85 percent of the terminal space may be occupied by baggage systems and other operating functions with which the passengers never come in contact.[38] They also suggested that baggage systems could cost as much as $100 million in the future at very large airports. It must be pointed out that this workshop preceded the problems with the baggage system at Denver International Airport, which has caused the opening of that airport to be delayed indefinitely at a cost of $8.8 million per month.[40] People movers, transporters, escalators, and elevators can represent 4 to 10 percent of the cost of the terminal. The workshop participants agreed that the best passenger terminals had the following items in common: a pleasant environment; efficient movement of people; logical circulation patterns; and clear directions and information.

One of the problems that needs to be addressed is that there are no standards for measuring the performance of the airport terminal building and services. Another problem is that the passengers, airport operators, the airlines and the FAA all have different interests in the performance of the terminal. Dr. Andrew Lemer has prepared a paper for the National Transportation Systems Center detailing some of the different viewpoints on the terminal's performance from the passengers', airlines' and airport operators' points of view.[33]

Measurements of Airport Terminal Performance from the Passengers' Viewpoint:

1. Compactness: curb to gate time and distance.
2. Delay and Service Times: check-in and waiting times, baggage claim time, etc.
3. Service Reliability: required time before departure, connecting time, alternative flight schedules and airlines, service levels variation.
4. Service Reasonableness: spatial logic, signing or sight lines, directness, service justice (first in - first out).
5. Cost: food and drinks, departure fees, connection fees, other concession prices.
6. Comfort and Diversion: crowding, noise levels, temperature and humidity, visual interest, choice of things to do, encourage sociability.

Measurements of Terminal Performance from the Airport Operators' Viewpoint:

1. Operational Effectiveness: passengers served, baggage handled, delays.
2. Efficiency: gate and space utilization, labor utilization, fuel consumption.
3. Risk: security effectiveness, safety, public health, crime.
4. Functionality: reliability, maintainability.
5. Finances: revenue yield, operations and maintenance expenses, debt service.
6. Flexibility: architectural and operational.

Measurements of Airport Terminal Performance from the Airlines' Viewpoint:

1. Operational Effectiveness: aircraft turnaround time, flight service times, baggage transfer reliability, passenger service times.
2. Station Cost: terminal fees, labor costs, equipment costs, inventory costs.
3. Corporate Image: control of space, design, service levels, market share.
4. Flexibility: operational and architectural.

In *Transportation Research Record 1199*, Ashford reports on different "Levels of Service" criteria that are used in several airports in Europe.[40] He reports that these level of service criteria are a result of the Highway Capacity Manual for measuring congestion and of work done by Fruin.

Ashford reports from his study that, for determining six different levels of service, Table 8.1 shows the required square footage for walkways, stairways, and queues, based upon Fruin's work with the New York Port Authority. These are represented as letter values from A through F in which A represents the best level of service and F the worst. The criteria are based upon the following three factors:

1. ability of an individual to choose walking speed;
2. ability to overtake;
3. ease of crossflow and reverse flow movements.

John Pararas is the Director of the Flight Transportation Laboratory at MIT, and the researcher has had discussions with him concerning the use of GIS or CAD for airport terminal modelling. He was working at that time on using the CAD software as the graphic engine for displaying the airport terminal for a simulation modelling program. He grouped airport models into three categories: queuing models, operations models, and decision making models.[41]

Table 8.1 Space requirement for Level of Service from Ashford

Level of Service	Walkways, (sq.ft)	Stairways, (sq.ft)	Queues, (sq.ft)
A	≥ 35	≥ 20	≥ 13
B	25-35	15-20	10-13
C	15-25	10-15	7-10
D	10-15	7-10	3-7
E	5-10	4-7	2-3
F	≤ 5	≤ 4	≤ 5

APPLICATION OF AIRPORT SIMULATION TO GIS

GIS provides a graphical basis for integrating physical dimensions and large amounts of data. It is proposed that GIS with the ability to integrate data and display physical characteristics and information can also serve as a foundation for running airport terminal models. Several GIS have the ability to call up external programs and integrate data.

The advantages of using a GIS for modelling is twofold. First, as with any CAD system, the ability to graphically display the terminal being modeled and graphically understand the results of the simulation is of great benefit to both the engineer and client. Second, GIS can also access various databases where current information is maintained. However, these two advantages can also, to a limited extent, be accommodated with a "SmartCAD".

The difference between CAD and GIS is that GIS can perform spatial analysis. An example of the application of spatial analysis to airport modelling would be one in which the graphics represent inputs to the model. Specifically, if a topological feature such as an arc, a node, or a polygon is moved in a GIS, the distances to other arcs and nodes are recomputed and updated. If the physical dimensional characteristics can be extracted and used as inputs to the model, then the model can be re-run every time a line representing a wall, ticket counter, or baggage claim area is moved.

EXPERIMENTAL ANALYSIS

A premise was developed such that the capacity and level of service of an airport terminal corridor could be modeled as a function of the width of the corridor and the model of the passenger flow. The premise was that CAD drawings of the airport terminal could be used for the graphics, a model developed, and a test run to relate width of corridor with capacity and level of service.

To test this premise, data were collected at Robert Mueller Airport in Austin. First, AutoCAD drawings were obtained of the airport terminal building. The drawings were successfully input into MicroStation for potential inclusion into a GIS.

Second, data were collected of passenger flows in the 643-foot-long corridor of the passenger terminal by videotaping the corridor in two locations during the busiest day of the year, the day before Thanksgiving. The videotapes were then painstakingly reviewed to record the passenger flow levels at each minute interval in both directions. This passenger flows were then related to the arriving and departing flight schedule by gate.

The preliminary results of the data indicated that Robert Mueller did not have a capacity or level of service problem with the long corridor. Three additional gates had been added in the year before this analysis, which moved the Southwest Airlines passengers to another wing of the airport terminal. Previously, Southwest passengers had used the first two gates in the terminal; and, often, the number of passengers far exceeded the gate seating capacity, and the crowd in the hallway made walking through the hallway very difficult.

From the analysis, it was easy to calculate the unobstructed arriving passenger stream which passed the corridor in less than 10 minutes. The departing passengers were spread out over a longer period of time and often had multiple trips. There was a certain base level of activity in both directions even during periods when no flights were scheduled. The only congested time period, which only lasted a few minutes, occurred when two arriving passenger streams collided with a surge of passengers responding to a boarding call at a third gate.

Although it appears possible to complete the demonstration by developing a model for the hallway passenger flows and operating it within a GIS, this process was not completed for a lack of resources. The hallway was well sized and would require the simultaneous arrival of three aircraft to really bog down. This was not considered a prudent design goal, since Robert Mueller operates on a single air carrier runway which causes some time delay between aircraft arrivals.

The conclusions of the test were that recently developed CAD software could provide some graphic output for the level of service or the predicted number of passengers in the terminal at any one time. Although GIS could probably perform this graphic function, the forecast need for airport staff to perform this modelling simulation was not great. Therefore, at this time it is not recommended that GIS be used for modelling airport terminal buildings unless the GIS already exists and the model selected happens to be graphically compatible.

SUMMARY

Airport terminal modelling can be very important at airports. Modelling of the airport taxiways and runways for capacity and delay with SIMMOD is becoming quite common. Graphics can improve the output of these models, but the models are not routinely used by airport staff.

An experiment was developed at Robert Mueller Airport in Austin with the premise being that CAD drawings of the airport terminal could be used for the graphics portion of the model, a model was developed, and a was test run to relate width of corridor with capacity and level of service. The conclusions of the test were that CAD and GIS software could provide the graphic output for level of service or predicted number of passengers in the terminal.

However, the need for airport staff to perform this modelling simulation is not great and a graphics capability exists with some of the models themselves. Therefore, at this time it is not recommended that GIS be used for modelling airport terminal buildings unless the GIS already exists and the model selected happens to be graphically compatible.

CHAPTER 9. GIS STANDARDS

Airports in the process of developing a new GIS must consider what standards exist relating to GIS. Every GIS is a customized system, but no agency operates in a vacuum. Eventually an airport may want to import data from an outside agency or a surrounding community. Also, if someone else has the responsibility to keep the data up to date, the airport will want the capability to receive updates as well. This chapter discusses the current developments in GIS standards.

There really are no national standards for how a GIS must be developed. Efforts have been made to force federal agencies to adopt standards for transferring data between GIS systems and standards for documenting the GIS development. As described more fully in this chapter, these standards do not describe what should be included in a GIS, what levels of precision are required, what features or attributes must be included, or what color standards or graphic standards should be used to represent certain features.

However, the important point to remember is *not* that these voluntary federal standards do not necessarily apply to airports, but that they *should* seriously be considered for adoption to the extent they are affordable for airports. However, what is most important is that the *airport must set a standard for the development of the GIS* that permits the future functionality of the system while maintaining data security, integrity and accuracy, and proper documentation of the data lineage. Any standard is far better than no standard at all. DFW airport hired a consultant to develop their GIS and CAD standard as part of the initial tasks in the development of the GIS. The DFW standard, which is over 50 pages long, borrows from the US Corps of Engineers, who are developing a Tri-service CAD and GIS standard.

If the standards for horizontal positional accuracy are set too low it may be costly to go back and add applications at a later date. Proper planning and a small pilot project are necessary ingredients for successful efficient implementation of an airport GIS. In planning a GIS, look at the potential future uses of the GIS and set your standards accordingly. Different sources of graphic data have different limitations and different horizontal positional accuracy. A digitized copy of a USGS map will not have the same relative positional accuracy as a rectified photograph or a digital orthophoto.

FEDERAL SPATIAL DATA TRANSFER STANDARD

The Spatial Data Transfer Standard (SDTS) is a federal information processing standard (FIPS 173). All federal agency purchases of spatial data systems including GIS that either will share data or have the potential to share data must be compatible with the SDTS. The FIPS 173 is mandatory for all federal agencies and is only voluntary for non-federal agencies. Currently, four such federal GIS systems are under procurement, and special SDTS translators are being written to fulfill the requirements of the standard. The important distinction to understand is that FIPS 173 is a transfer standard and not a standard that specifies what data must be included in a GIS or how the data is stored or manipulated in the GIS.

Since development of the database can be as much as 80 percent of the cost of developing a GIS, any effort that reduces the cost of developing the spatial database could be significant. The purpose of SDTS is develop a standard such that spatial information already prepared can be exchanged or imported reducing development costs. The global theory is that if all of the national available information can be used, a savings in development costs will result.

The difference between a statewide GIS and an airport GIS is that significant GIS data files exist that could eventually make adoption of the standard beneficial for the statewide GIS. In an airport GIS, the geographical area is relatively small, and federal, state, or municipal GIS, generally have little data to contribute to the development of the airport GIS. With the exception of the management of noise mitigation or noise analysis, there is little need for spatial information from outside the airport boundaries. And since there is even less need for the airport to share its spatial data with other agencies, the case for adoption of full compatibility of SDTS standards in not compelling.

Airports (except for Dulles, Washington National, and Atlantic City) are not federally owned and would not transfer spatial data to federal agencies; therefore, currently airports do not have to specify FIPS 173 in their procurement of a GIS. It will take about five years until the SDTS really begins to become effective. The standard will not become truly effective until the translators are readily available from GIS vendors. Currently, some digital data are available from USGS and the Census Bureau in SDTS format, but these data are available only by special request and would be provided at additional cost.

Currently, there is no advantage for non-federally-owned airports to specify that the GIS procurement be able to transfer spatial data in SDTS format. Currently, there are no spatial data that airport may wish to import into their GIS that cannot be imported either by direct or indirect conversion. Examples of possible imports of spatial data might be the use of Census TIGER files or imports of GIS files from neighboring community-owned GIS. Most GIS software packages already support the import of TIGER files, and software is already written to translate between ARC/INFO and MGE GIS.

Most commercially available GIS software packages will at some time in the future develop software to translate spatial data in SDTS format. However, there will no guarantees that the translators will convert 100 percent of the topological structure of the SDTS format file to the topological structure used by the user's GIS. In fact, the USGS expects to have a specific testing program which will be necessary to certify what capability each translator can accomplish.

The SDTS standard has two profiles that have been approved: Topological Vector Profile and Raster Profile. Other profiles will be developed over time. The translators must be tested to verify performance for each part of the profile and for each hardware and software combination.

The second important point about SDTS is that over time it eventually will become a standard with which each major software vendor will attempt to comply. In fact, several states such as Virginia and Texas may adopt the standard either as a mandatory or as a voluntary standard as well. Only time will tell how important this standard will become and the impact it will have on GIS being developed.

STATE STANDARDS FOR GIS DOCUMENTATION

States such as Texas are considering adopting standards for GIS development. Texas, for instance, has a state agency, the Department of Information Resources, which has the authority to act as a clearinghouse for information, including geographically referenced information. The Department has also prepared a standard for documentation of GIS data. The standard is mandatory for state agencies and state universities. The documentation is a paper form and contains good information about the contents of the GIS, the lineage of the data, the accuracy, and how it was converted into spatial data.

The Texas standard for documenting a GIS is provided in Appendix D for the demonstration GIS developed for this project.

EXECUTIVE ORDER 12906

April 11, 1994, President Clinton signed Executive Order 12906 which calls for the creation of a coordinated National Spatial Data Infrastructure to support public and private sector applications of geospatial data in such areas as transportation, community development, agriculture, emergency response, environmental management, and information technology. The order defines National Spatial Data Infrastructure (NSDI) as "the technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data." The order also defines geospatial data as "information that identifies the geographic location and characteristics of natural or constructed features and boundaries on the earth. This information may be derived from, among other things, remote sensing, mapping, and surveying technologies. Statistical data may be included in this definition at the discretion of the collecting agency."

The effect of the Executive Order, while far reaching in scope, does not have the same regulatory requirements on the federal government as does FIPS 173 and the SDTS. The Executive Order is being recognized buy many federal agencies and their intentions are to try and comply with the many requirements in the Order, but none of the requirements are compulsory for any federal agency. The Executive Order does not impose requirements for federal procurements as does FIPS 173. However, one significant requirement of the Executive Order is that all federal agencies begin standardized documentation of all new collected geospatial data. The new standards being developed for documenting the geospatial data, commonly referred to as metadata, will most likely become a FIPS, probably within 1-3 years.

The Executive Order has several significant provisions:

1. It defines the Executive Branch leadership for geospatial matters as the Federal Geographic Data Committee (FGDC) which is an interagency committee established by OMB Circular A-16.
2. It calls for the establishment of a National Spatial Data Infrastructure (NSDI).
3. It calls for the establishment of a National Geospatial Data Clearinghouse.
4. It orders the establishment of standardized documentation of geospatial data (standardized metadata).
5. It requires federal agencies to plan for public access to geospatial data.
6. It requires the FGDC to plan for the completion of the initial implementation of a National Digital Geospatial Data Framework by the year 2000.

FEDERAL STANDARDS FOR GEOSPATIAL METADATA

In June 1994, after several years of work, the Federal Geographic Data Committee has produce the draft of the Content Standards for Digital Geospatial Metadata. This document is developed as a guide for federal agencies to document their geospatial data. Metadata, or data about data, describes the content, quality, condition, and other characteristics of data. The FGDC has tried to coordinate their standards for metadata with the SDTS standard as closely as possible such that all metadata can be transferred under FIPS 173.

The current June 8, 1994 standard is a draft that will probably be revised after comments and use. Eventually, it will most likely lead to a metadata standard that will be mandatory for federal agencies.

Airports considering the development of a GIS or acquiring geospatial data should review the FGDC Content Standards for Digital Geospatial Metadata. Although the standard is not mandatory and making the standard mandatory for the development of an airport GIS may not have immediate pay back, the standard does stimulate thinking in the development and documentation of geospatial data.

The reasoning behind the standard is that a well documented data set provides good information about the data. Too many data sets are developed for one specific application and when a second application is considered for the data, little or no documentation exists to determine if the data is adequate for the second application. Data that are inadequately documented can become useless if the key personnel who developed the data are no longer available.

The metadata standard submitted for adoption by the federal government is expected to save money in the long term because the documentation can be very valuable in determining the fitness of the data for applications. For airports with geospatial data, it is recommended that the data be well documented. However, it must be evaluated as to whether the cost of documenting the data in compliance with the FGDC standard is cost effective since in most cases the airport will be the sole user of the data.

NATIONAL SPATIAL DATA INFRASTRUCTURE (NSDI)

It is unlikely that the NSDI will ever be a single agreed-upon set of data representations for the US or a national GIS. Most likely it will include a large collection of multiple representations of geography and geospatial data that meet some of our needs.

There is not an official definition of what is NSDI but the FGDC has said that most people could agree that "NSDI consists of organizations and individuals who generate or use geospatial data, of the technologies that facilitate use and transfer of geospatial data, and of the actual data." In simpler terms planning for NSDI is preparing for an information based society or in the common vernacular its building the "information highway."

Although the FGDC has been tasked with providing a plan for implementing NSDI, it will be a long term, interactive project that anyone interested can participate. The FGDC regularly solicits input and anyone with an Internet address can easily participate.

Airports must realize what NSDI is not. It is not a national GIS standard to which all airport GIS should conform. There probably will never be such a GIS standard. However, there may be significant benefits from participating in the NSDI. Before developing a new GIS standard, airports should see what other standards are available. The FGDC encourages participating in the development of national standards and trying out draft standards. The NSDI will be built with partnerships from users, vendors, government and academia.

RECOMMENDATIONS

1. All airport regardless of size should set a CAD standard and provide all consultants a "seed file" or computer base map from which all drawings should be submitted.
2. Airports should develop a long range geographic information planning document that outlines potential GIS application and users.
3. Airports should review other airport GIS and CAD specifications and applicable state or federal standards. It is particularly recommended that the Tri-service CAD and GIS standards available from the Corps of Engineers at Vicksburg, Mississippi and the Dallas/Fort Worth Airport standards be reviewed.
4. Airport should develop or hire an experienced and knowledgeable consultant to develop the airport GIS standards and specifications.

CHAPTER 10. SUMMARY, ANALYSIS, CONCLUSIONS AND RECOMMENDATIONS

This chapter provides an analysis of the potential for implementation of GIS at airports and the prognosis is good. This chapter also presents the author's conclusions and recommendations on how to implement an airport GIS.

SUMMARY

Airport GIS is being developed at several airports. Although most often a single specific application was the impetus for development, additional applications are being added or planned at every airport that has a GIS. The forecast indicates that airport GIS is entering a dynamic growth phase, with the busiest airports most likely to develop an airport GIS or add applications.

Pavement management is an excellent application for airport GIS with potential savings through better management. Specifications were developed for airport GIS related to pavement management including recommendations of database structure, horizontal accuracy, compatibility with imaging and CAD software, feature requirements, and spatial operations requirements.

Management of lease space with GIS has been successfully implemented at Boston Logan International Airport. Dallas/Fort Worth Airport is developing a GIS to manage lease space and utilities. Any airport with a significant amount of lease space or other infrastructure could justify a small GIS system, if there are frequent changes to the data, multiple tenants or customers, multiple users of the data, and the use of the data can be enhanced by visual presentation. The use of the Global Positioning System (GPS) is also popular with a GIS to indicate position.

The Environmental Protection Agency requires airports to prepare a storm water pollution prevention plan (SWPPP). AAAE has recently prepared a sample SWPPP which can be used as a model for other airports to use in the preparation and update of individual plans. The FAA is also preparing an advisory circular to provide guidance on SWPPP. The purpose of the SWPPP for airports is to reduce the flow of deicing chemicals or fuel spills into the storm sewer, to eliminate illicit connections to the storm sewer system, and institute best management practices and training to prevent pollution from occurring.

Although a GIS is not necessary to comply with EPA guidelines, all of the required items in a SWPPP can be stored and displayed in a GIS and will permit better visualization of the data that is being managed. A GIS can help managers determine if required inspections and training are being updated.

Sample specifications and suggestions of what should be included in a storm water GIS were listed. A GIS for use in compliance with EPA guidelines for a SWPPP should contain all the required items for that particular state and airport. Most of the required items are readily visible on a base map. However, additional requirements such as documentation of inspections can be contained in a relational database. As potential fines and criminal penalties are possible, care should be taken to comply with all EPA requirements.

The day night level (Ldn or DNL) is the approved sound metric for all federal noise mitigation measures and the FAA Integrated Noise Model (INM) is the approved method of calculating noise contours at airports. Noise mitigation programs are very costly and airports generally rely on federal funding for Part 150 noise mitigation programs. As an example, the cost of noise mitigation for the new runway at DFW nearly equals the construction cost.

GIS can be an important tool for engineers, planners, and administrators for analysis, mitigation management and monitoring programs for aircraft noise. Integration of INM with GIS will be more easily accomplished with the future release of INM Version 5. The engineer or planner who analyzes the noise contours must understand all the operational variables, FAA and airport flight restrictions, and airline and pilot noise abatement procedures. Proper analyses can permit airport and FAA decision makers and the airlines to make choices about operating procedures, thus affecting noise contours that can determine the costs of noise mitigation as well as the number of persons adversely affected by noise. Integration of INM with GIS permits the airports to understand the consequences of alternative operating procedures by performing comparative cost benefit analyses.

A demonstration was performed using OAG scheduled flight data for DFW Airport and calculating the comparative noise contours for two operating scenarios. The example showed a 3 square mile reduction in the area of the 65 Ldn noise contour by restricting takeoffs at evenings and nights from the runway currently under construction. The noise contours can be converted into topological features and analysis can be made of the number and addresses of dwellings within the comparative contours.

Suggested specifications for GIS software for full integration with the INM Version 5 include the ability to spatially analyze what lies within or outside the noise contour polygons, manipulate the OAG flight schedule, and change the geometry of flight tracks with CAD. Suggested specifications for GIS for management of a noise mitigation program should include an accurate base map with dwelling locations as topological features matched to an attribute database with complete postal address.

Noise monitoring is becoming more common place at the busier airports and can be funded in the Part 150 noise management program. The more sophisticated noise monitoring systems can use GIS to display the radar track of the subject aircraft, match the aircraft to a noise event at a microphone, and geographically match complaint calls to noise events.

What a combined GIS and noise monitoring program does best is to reduce the emotions of the issue and allow discussion and education to take place with the required public involvement. GIS specifications with a noise monitoring system should include the hardware requirements, the GIS and attribute software, what is to be displayed, the users of the system, and what spatial analysis will be performed on the data.

GIS standards are very important in the development of an airport GIS and prior planning for future applications can save costs. Federal standards should be reviewed and implemented where cost effective.

ANALYSIS OF THE POTENTIAL FOR AIRPORT GIS IMPLEMENTATION

Geographical information systems will become common at airports in the near future. The results of the survey in Chapter 2 indicated that 58 percent of all responding airports expect to have a GIS by the end of 1997. With over 500 airports being served in the United States by the regional airlines in 1993[42], there seems to be a large potential market for airport GIS. Of the airports in the survey that have at least one GIS application, all are considering additional applications for GIS. GIS for transportation (GIS-T) has a strong foothold in the highway sector, but there is good potential for GIS in the airport industry. The number of airports which will actually implement a GIS within the next 36 months will depend on several factors:

1. The financial health of the airline industry.
2. Whether FAA continues to ignore the development of GIS at airports or begins to encourage and support it.
3. The financial health of the airport.
4. The level of computer literacy of the airport staff.
5. The amount of education and training provided by support groups such as the American Association of Airport Executives and the Airport Consultants Council.
6. Whether or not a champion exists who wants the GIS and is willing to work toward implementation.
7. The attitude and stance taken toward GIS by the Airline Transport Association and Regional Airline Association.
8. The level of effort that airports will put forth in developing the key applications that GIS can improve: pavement management systems, project management systems, noise management systems, and storm water pollution prevention plans.

As the success stories of airports using GIS become more widely known, other airports will begin to investigate GIS. In the near future, as federal regulations require airports to actually develop the maps for storm water pollution prevention plans and as new master plans and noise studies are performed, airports will become more computer literate with respect to computer-aided drafting (CAD). As the ability to cope with CAD increases, more and more airports will turn to GIS to provide them with better tools for airport engineering and management.

The airline industry is showing signs of growth even though the major carriers are in a cost-cutting mode. The regional airlines posted a 12 percent growth in revenue passenger miles in 1993, and the availability of GPS approaches may increase the number of airports certified under Part 139 for airline operations. Although the number of revenue passenger miles is expected to increase, the number of airports serving metropolitan cites is remaining the same. Only two new major airports are currently under construction, Denver and Austin, and both are replacement airports. Therefore, the outlook is good for new construction at our nation's existing airports.

The cost of developing the data is the major cost in implementing GIS. Sources of graphic data such as USGS Digital Line Graphs and Orthophotos are becoming more readily available. The emergence of GPS data collection tools for mobile mapping is greatly reducing the cost of custom digitizing of features and attribution. More consultants are gaining experience in the development of successful GIS. As a result, the cost of GIS implementation for the same size of scope project is being reduced.

The previous chapters showed how a GIS could be implemented for pavement management, infrastructure management, storm water pollution prevention plans (SWPPP), and project management and for noise analysis, mitigation, and management. Each of these is a viable application for airport GIS. The application of modelling airport terminal buildings, although an excellent analytical tool, is not recommended for use as an airport-funded GIS. Basically, the models are so specialized that airports engineers and managers will not use these models without specialized airport consultants.

CONCLUSIONS

The objective of this research was to support the premise that airport authorities should develop multiple user, multiple application, geographical information systems for airport managers and staff to use as a significant tool for airport engineering and management. This research report has concluded that the premise is correct. The following items have been presented to support this conclusion.

1. The survey of airports conducted indicated that most airports (58 percent) have plans for implementing an airport GIS within three years. Even though most initial GIS implementations were developed for a single application, plans are definitely moving toward multiple applications and hence multiple user systems.
2. The report provides a detailed description of the application of airport GIS for the following critical airport engineering and management functions:
    a. pavement management
    b. lease space and utility management
    c. storm water compliance
    d. noise analysis, mitigation and monitoring
    e. management of airport projects
3. The report provides sample specifications and discusses the industry standards that an airport should review when preparing a plan for implementing a multiple user, multiple application GIS.
4. The author has developed a small demonstration GIS capable of demonstrating some of the GIS functionality for pavement management, noise analysis, and storm water management applications.

RECOMMENDATIONS FOR AIRPORTS CONSIDERING GIS

1. Upgrade the CAD capability of the airport. Set CAD standards and have all consultants deliver CAD products with their contracts. Upgrade the airport's CAD hardware and operator training if necessary.
2. Determine whether any applications have funds for potential implementation of a GIS. If AIP funds or planning grants are available for a SWPPP, a master plan, a Part 150 study, or any other of the compatible applications, determine whether a pilot project GIS can be developed as part of that project.
3. Determine information management goals and determine which parts of the organization would use a GIS or better information management system. Even though a GIS can provide better engineering tools, do not neglect the business aspects of better information management that might be provided by a GIS.
4. Select hardware and software for a GIS in relation to the ultimate growth capability of the potential system. A common problem in GIS implementation is that a small system is chosen first to save money and no one wants to learn a new system. Some GIS software available today has very little growth potential and is severely limited in the spatial analysis capability. The hardware and software are minor costs of an implementation, and these should be purchased with the potential to grow to a very large system over time. Purchasing GIS software that is compatible with CAD drawings is essential for airports. Purchasing GIS software with the capability to display images in the background is highly recommended.
5. Write specifications for complete development and implementation of a GIS for one or two applications. Write your data acquisition specifications with other potential GIS applications in mind such that a small increase in funding or work can allow other applications to be implemented inexpensively.

6. Designate a GIS manager or hire a full-time GIS manager. Give that person the authority to work across traditional organizational boundaries for the development of the growth version of the GIS. That person needs support from all levels of the organization for successful implementation.

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APPENDIX A
AIRPORT GIS QUESTIONNAIRE AND RESULTS

AIRPORT GIS QUESTIONNAIRE

Name:____________________ Title: ____________________

Department: ____________________ Phone # ____________________

1. What is your airport name & identifier? ____________________ ________
2. What was the approximate number of operations last year? __________
3. Approximately how many acres are within the airport boundary? __________
4. Does your airport currently use a GIS? YES / NO
5. If the answer to question 4 is NO, does your airport currently have a GIS under development or have firm plans to begin developing a GIS within the next 12 months? YES / NO
6. If the answer to question 4 and 5 is NO, does your airport have plans to begin developing a GIS within the next 3 years? YES / NO
7. For the next section please mark YES/NO if your airport is actually using or planning to use GIS for the following potential list of GIS applications at airports.

LIST OF POTENTIAL GIS APPLICATIONS AT AIRPORTS	ACTUAL USE:	PLANNED USE:
Management of leasable space	YES / NO	YES / NO
Management of airport pavements	YES / NO	YES / NO
Management of utilities	YES / NO	YES / NO
Management of airport properties	YES / NO	YES / NO
Management of off-airport properties (such as a noise mitigation program)	YES / NO	YES / NO
Management or tracking of noise complaints	YES / NO	YES / NO
Integration with noise contour calculation program (such as integrated noise model)	YES / NO	YES / NO
Integration with noise monitoring equipment	YES / NO	YES / NO
Management of storm water or preparation of a storm water pollution prevention plan	YES / NO	YES / NO
Analysis of the effects of schedule or operational changes on noise contours or noise mitigation programs	YES / NO	YES / NO
Geographic analysis of any kind	YES / NO	YES / NO

Please mail to: M. McNerney, CTR, 3208 Red River Suite 200, Austin, TX 78705

Airport	ID	Operations	Acres	GIS?	12 Months?	36 Months?	Leasable Space	Pavement Management	Utilities	Management of Airport Properties	Management of Off-Airport Properties	Noise Complaints	Integration with INM	Integration with Noise Monitoring	Management of Storm Water	Analysis of Noise Contours	Geographic Analysis	Display Raw Data	Display Queried Data	Management of Gates	Management of Ground Support Equipment	Check for Database Errors	Other
Chicago O'Hare International	ORD	832,500	7,700	Y			P	P	P	P			P	P	P	P	P	A	A	P	A	A	
Dallas/ Fort Worth International	DFW	764,243	17,637	N	Y		P	P	P	P	P	P	P	P			P	P	P			P	P
Atlanta	ATL	621,000	4,000	Y			P	A	A	A	A		A		P	A		A	P	A		P	A
John Wayne Airport	SNA	548,710	504	Y			P	P	P	P					P								
McCarran International	LAS	540,000	2,800	N	N	N																	
Miami International & 5 others	MIA	496,822	6,500	Y			A	A	A	A	A	A	A	P	A	P	A	A	A	A	A	A	
Phoenix Sky Harbor	PHX	465,000	2,400	N	N	N																	
Minneapolis-St. Paul International	MSP	439,990	3,300	Y			P	P	P	P	A	A	A	A	P	A	P	P	P			P	
Long Beach Municipal	LGB	431,000	1,166	Y			P	P		P			A		P	P	P	P	P	P			P
Newark International	EWR	411,000	2,500	N	N	Y	P	P	P	P	P	P	P	P	P	P	P	P	P	P			
Honolulu International	HNL	403,630	2,230	N	N	Y		P	P	P	P		P	P	P	P	P						P
Philadelphia International	PHL	397,000	2,200	N	N	N																	
Memphis International	MEM	346,181	4,500	Y			A			A	P				A		A	A	A			A	
Seattle- Tacoma International	SEA	346,000	2,500	N	N	Y			P		P	P	P	P		P	P	P	P	P	P	P	
Houston Intercontinental	IAH	326,886	7,800	Y			A	P	A	P	P	P	P		A	P	P	A	A	P		A	
LaGuardia Airport	LGA	325,000	500	N	N	Y	P	P	P	P	P	P	P	P	P	P	P	P	P	P			
John F. Kennedy International	JFK	322,000	5,000	N	N	Y	P	P	P	P	P	P	P	P	P	P	P	P	P	P			
Cincinnati/ Northern Kentucky International	CVG	305,544	5,800	N	N	N																	
Orlando International	ORL	304,084	15,000	N	Y		P	P	P	P	A	A	A	A	P	A	A	P	P			P	P
Washington National	DCA	301,668	700	N	N	Y	P		P									P	P				
Nashville International	BNA	285,000	4,400	Y			A	A	A	A	P	A	A	P									
Raleigh - Durham International	RDU	275,000	5,000	N	N	Y	P	P	P	P	P	P		P	P	P	P	P	P				
Washington Dulles International	IAD	267,000	10,900	N	N	N																	
Tulsa International	TUL	260,000	4,000	N	Y		P		P								P						
Tampa International	TPA	250,000	3,300	N	N	N																	
Anchorage International	ANC	240,928	4,500	N	N	Y	P	P	P	P					P		P						
Tuscon International	TUS	228,877	3,900	Y							P	A					P	P	P				

Airport	ID	Operations	Acres	GIS?	12 Months?	36 Months?	Leasable Space	Pavement Management	Utilities	Management of Airport Properties	Management of Off-Airport Properties	Noise Complaints	Integration with INM	Integration with Noise Monitoring	Management of Storm Water	Analysis of Noise Contours	Geographic Analysis	Display Raw Data	Display Queried Data	Management of Gates	Management of Ground Support Equipment	Check for Database Errors	Other
Dallas Love Field	DAL	213,527	1,300	N	N	N																	
San Diego International	SAN	213,000	480	N	N	N																	
Fort Lauderdale - Hollywood International	FLL	210,000	1,300	Y			A		P	A	A						A	A	A				
Albuquerque International	ABQ	208,000	2,200	N	N	Y	P	P		P					P		P	P		P		P	
Greater Rochester International	ROC	205,388	1,136	N																			
Mitchell International	MKE	203,030	2,100	N	N	Y	P	P	P	P	P	P	P	P	P	P	P						
St. Petersburg- Clearwater International	PIE	189,000	2,000	N	N	N																	
Robert Mueller Municipal	AUS	186,000	711	N	N	Y	P	P	P	P		P	P	P	P	P	P	P	P			P	
Kansas City International	MCI	178,000	9,500	N	N	N																	
Syracuse Hancock International	SYR	177,200	2,000	N	Y		P	P	P	P		P					P	P	P		P	P	
Chicago Midway	MDW	177,000		Y			A		P	A	P				P			A	A				
Wichita Mid-Continent	ICT	175,000	3,400	Y			A	A	A	A					P								
Reno Cannon International	RNO	162,604	1,400	N	Y		P	P	P	P	P	P	P	P	P	P	P	P	P			P	
Will Rogers World	OKC	160,000	7,800	N	Y		P	P	P	P		P			P		P	P	P			P	
Sarasota - Brandenton International	SRQ	156,549	1,102	Y			A	P	P	A	P	A	A	A	P	A	A		A	A			
El Paso International	ELP	155,000	7,000	N	N	N																	
Standiford & Bowman Fields	SDF	153,612	1,100	N	N	N																	
Richmond International	RIC	149,000	2,352	N	Y		P		P	P	P				P		P						
Eppley Airfield, Omaha	OMA	145,704	2,625	Y			A	A	A	A	A	A	A		A		A	A	A	A		A	A
Jacksonville International	JAX	145,000	7,700	N	Y					P	P												
Boise Air Terminal	BOI	140,985	4,900	Y			A	P	P	A	A	A	A	P	P	P	P	A	A			A	A
New Orleans International	MSY	140,000	1,500	Y			P		P	A	A	A	A	A	P	P	A	A	A				
Blue Grass	LEX	140,000	900	N	N	N																	
Norfolk International	ORF	136,313	1,300	N	N	N																	
Dayton International	DAY	134,500	4,400	N	N	Y						P	P	P		P							
Grand Rapids	GRR	134,358	3,000	N	Y		P	P	P	P	P	P	P	P	P	P	P	P	P				
Baton Rouge Metropolitan	BRT	132,739	2,000	N	Y		P	P		P	P	P			P	P	P	P	P	P		P	

Airport	ID	Operations	Acres	GIS?	12 Months?	36 Months?	Leasable Space	Pavement Management	Utilities	Management of Airport Properties	Management of Off-Airport Properties	Noise Complaints	Integration with INM	Integration with Noise Monitoring	Management of Storm Water	Analysis of Noise Contours	Geographic Analysis	Display Raw Data	Display Queried Data	Management of Gates	Management of Ground Support Equipment	Check for Database Errors	Other
McGhee Tyson	TYS	127,877	2,500	Y			A	P	P	P	A		A		P		A	A	P			A	
Pensacola Regional	PNS	120,000	1,350	N	N	N																	
Juneau International	JNU	115,000	630	N	N	N																	
Reading Regional	RDG	104,000	870	N	N	N																	
Savannah International	SAV	102,874	3,573	N	N	N																	
Abilene Regional	ABI	100,000	1,700	N	N	Y	P	P	P	P					P		P						
Key West International	EYW	100,000	176	N	N	N																	
Midland International	MAF	92,500	1,570	N	N	N																	
Amarillo International	AMA	92,000	3,500	N	N	N																	
Montgomery Danelly Field	MGM	90,000	1,900	N	N	N																	
Mathis Field	SJT	90,000	1,478	N	N	N																	
Rickenbacker International	LCK	85,000	5,000	N	Y		P	P	P	P	P	P					P	P	P			P	P
Lafayette Regional	LFT	85,000	1,116	N	N	Y	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	
Fort Smith Regional	FSM	85,000	1,400	N	N	N																	
Pueblo Memorial	PUB	84,103	2,200	N	N	N																	
Klamath Falls International	LMT	80,000	1,100	N	Y		P	P	P	P					P		P	P	P			P	
Cedar Rapids	CID	80,000	3,100	N	N	N																	
Easterwood	CLL	80,000	750	N	N	N																	
Greenville- Spartanburg	GSP	75,000	2,500	N	N	N																	
Gulfport- Biloxi Regional	GPT	70,707		Y			P			A													
Erie	ERI	67,983	800	N	N	N																	
Waco Regional	ACT	62,067																					
Cheyenne	CYS	60,203	856	N	N	N																	
Brownsville / South Padre Island	BRO	60,000	1,700	N	N	N																	
Gary Regional	GYY	55,000	670	N	N	N																	
Barkley Regional	PAH	45,000	880	N	N	Y			P	P					P		P	P	P			P	
Danville Regional	DAN	40,000		N	Y					P	P				P		P	P					

APPENDIX B
MICROPAVER DATA FIELDS AND CODES

MicroPAVER Data Fields

I. PAVEMENT DEFINITION

BRANCH NUMBER	5 ALPHA NUMERIC	R1230
BRANCH NAME	25 ALPHA NUMERIC	RUNWAY 12-30
BRANCH USE	7 ALPHA	APRON HELIPAD MTRPOOL OTHER PARKING ROADWAY RUNWAY STORAGE TAXIWAY
NUMBER OF SECTIONS	4 INTEGER	
BRANCH AREA	DECIMAL 9.2	< 10,000,000 (SF)
REMARKS	TWO 35 ALPHA ROWS	RUNWAY IS 150 FT WIDE
SECTION NUMBER	2 ALPHA NUMERIC	A1 (FIRST DEFAULT)
FROM	25 ALPHA NUMERIC	LOCATION INFO
TO	25 ALPHA NUMERIC	LOCATION INFO
ZONE	4 ALPHA NUMERIC	OPTIONAL DESCRIPTOR
SECTION CATEGORY	1 ALPHA NUMERIC	OPTIONAL DESCRIPTOR
PAVEMENT RANK	1 ALPHA (REQUIRED)	A = PRINCIPAL B = ARTERIAL C = COLLECTOR D = INDUSTRIAL E = RESIDENTIAL N = NOT APPLICABLE P = PRIMARY S = SECONDARY T = TERTIARY X = OTHER
SURFACE TYPE	3 ALPHA (REQUIRED)	AAC = asphalt over AC ABR = asphalt over brick AC = asphalt concrete ACT = asphalt over CTB APC = asphalt overlay PCC APZ=asphalt over pozzolanic base BR = brick COB = cobblestone GR = gravel PCC=portland cement concrete PVB = paving blocks ST = surface treatment X = other
SECTION LENGTH	DECIMAL 9.2	< 10,000,000
SECTION WIDTH	DECIMAL 9.2	< 10,000,000
SECTION AREA	DECIMAL 9.2 (calculated)	< 10,000,000 (warning)
LAST CONSTRUCTION	DATE MMM/DD/YYorYYYY	APR/15/1993 or APR/15/93
SLAB LENGTH	DECIMAL 9.2	< 10,000,000
SLAB WIDTH	DECIMAL 9.2	< 10,000,000
NUMBER OF SLABS	6 INTEGER (calculated)	(warning do not exceed limits)
JOINT LENGTH	DECIMAL 9.2 (calculated)	JL=(sect len/slab len)*sect wd =(sect wdth/slab wd)*sect len

II. Inspection Data

BRANCH NUMBER	5 ALPHA NUMERIC	R1230
SECTION NUMBER	2 ALPHA NUMERIC	A1 (default first value)
INSPECTION DATE	DATE MMM/DD/YY orYYYY	APR/15/93 or 1993
RIDING QUALITY	3 ALPHA NUMERIC	optional - any scale
SAFETY	3 ALPHA NUMERIC	optional - any scale
DRAINAGE CONDITION	3 ALPHA NUMERIC	optional - any scale
SHOULDER CONDITION	3 ALPHA NUMERIC	optional - any scale
OVERALL CONDITION	3 ALPHA NUMERIC	optional - any scale
F.O.D. POTENTIAL	3 ALPHA NUMERIC	optional - any scale
TOTAL # SAMPLES	3 INTEGER	required number in section
SAMPLE NUMBER	3 ALPHA NUMERIC	
SAMPLE TYPE	1 ALPHA	R = RANDOM A= ADDITIONAL
SAMPLE UNIT SIZE	8 INTEGERS	SF FOR AC NUMBER SLABS FOR PCC
DISTRESS CODE	2 INTEGER	SEE TABLE 1 & 2
DISTRESS DESCRIPTION	ALPHA NUMERIC	SEE TABLE 1 & 2
SEVERITY	1 ALPHA	L = LOW M = MEDIUM H = HIGH
QUANTITY (DISTRESS)	DECIMAL 9.2	< 10,000,000 some distresses have default quantity

II. B INSPECTION DATA USED TO CALCULATE DATA VALUES

DENSITY: quantity/sample unit size	DECIMAL 5.2	100.00 PERCENT MAX
DEDUCT VALUE: calculated from table	DECIMAL 3.1	99.9 MAX
PCI formula calculation using number of distresses and deduct values	DECIMAL 3.0	100 MAX
RATING Based upon translation of PCI score	ALPHA	0-10 = FAILED 11-25 = VERY POOR 26-40 = POOR 41-55 = FAIR 56-70 = GOOD 71-85 = VERY GOOD 86-100 = EXCELLENT
Climate Percent Deduct Value	DECIMAL 4.1	100.0 MAX
Load Percent Deduct Value	DECIMAL 4.1	100.0 MAX
Other Percent Deduct Value	DECIMAL 4.1	100.0 MAX
STANDARD DEVIATION	DECIMAL	

TABLE 1 ASPHALT DISTRESS

Code	ROAD DISTRESS	Code	AIRFIELD DISTRESS	Mechanism
01	Alligator Cracking	41	Alligator Cracking	Load
02	Bleeding	42	Bleeding	Other
03	Block Cracking	43	Block Cracking	Climate
04	Bumps and Sags			Other
05	Corrugation	44	Corrugation	Other
06	Depression	45	Depression	Other
07	Edge Cracking			Load
08	Joint Refection cracking	47	Joint Refection cracking	Climate
09	Lane /shoulder drop off			Other
10	Longitudinal & transverse cracking	48	Longitudinal & transverse cracking	Climate
11	Patching & utility cut patching	50	Patching	Other
12	Polished aggregate	51	Polished aggregate	Other
13	Potholes			Load
14	Railroad crossing			Other
15	Rutting	53	Rutting	Load
16	Shoving	54	Shoving	Other
17	Slippage cracking	55	Slippage cracking	Other
18	Swell	56	Swell	Other
19	Weathering & raveling	52	Weathering & raveling	Climate
		46	Jet blast	Other
		49	Oil Spillage	Other

TABLE 2 PORTLAND CEMENT CONCRETE DISTRESS

Code	ROAD DISTRESS	Code	AIRFIELD DISTRESS	Mechanism
21	Blow-up/Buckling	61	Blow-up	Climate
22	Corner break	62	Corner break	Load
23	Divided Slab	72	Shattered Slab	Load
24	Durability (D) cracking	64	Durability (D) cracking	Climate
25	Faulting	71	Faulting	Other
26	Joint seal damage	65	Joint seal damage	Climate
27	Lane /shoulder drop off			Other
28	Linear cracking	63	Linear cracking	Load
29	Patching, Large	67	Patching, Large	Other
30	Patching, Small	66	Patching, Small	Other
31	Polished aggregate			Other
32	Popouts	68	Popouts	Other
33	Pumping	69	Pumping	Other
34	Punchout			Load
35	Railroad crossing			Other
36	Scaling, map cracking, crazing	70	Scaling, map cracking, crazing	Other
37	Shrinkage cracks	73	Shrinkage cracks	Climate
38	Spalling, corner	75	Spalling, corner	Climate
39	Spalling, joint	74	Spalling, joint	Climate

III. TRAFFIC DATA FIELDS

ROAD TRAFFIC:

BRANCH NUMBER	5 ALPHA NUMERIC	R1230
SECTION NUMBER	2 ALPHA NUMERIC	A1 (default)
TRAFFIC PERIOD	2 DATE FIELDS	FROM SEP/25/92 TO SEP/25/93
ADT (ONE WAY)	5 INTEGER	0 to 99999
PERCENT TRAFFIC DESIGN LANE	3 INTEGER	0 TO 100
PERCENT TWIN AXLE TRUCKS IN DESIGN LANE	3 INTEGER	0 TO 100
PERCENT TRUCKS W/3 OR MORE AXLES IN DESIGN LANE	3 INTEGER	0 TO 100
ANNUAL ESAL IN DESIGN LANE	5 INTEGER	0 to 99999 (THOUSANDS)
REMARKS	70 ALPHA NUMERIC	

AIRFIELD TRAFFIC:

BRANCH NUMBER	5 ALPHA NUMERIC	R1230
SECTION NUMBER	2 ALPHA NUMERIC	A1 (default)
TRAFFIC PERIOD	2 DATE FIELDS	FROM SEP/25/92 TO SEP/25/93
AIRCRAFT TYPE	ALPHA NUMERIC	C-5A, C-141 F-15E, F-4E
AIRCRAFT GROUP	ALPHA	CARGO FIGHTER
LOAD CATEGORY	ALPHA	HEAVY MEDIUM LOW
ANNUAL DEPARTURES	INTEGER	3000

APPENDIX C
SUMMARY OF INM AIRCRAFT DEPARTURES AT DFW AIRPORT

APPENDIX C
SUMMARY OF AIRCRAFT DEPARTURES AT DFW AIRPORT

AIRCRAFT	STAGE	DAY	EVENING	NIGHT	TOTAL
727200	1	41.58	10.86	1.00	53.44
	2	40.44	5.14	0.86	46.44
	3	18.71	4.00	0.00	22.71
727Q15	1	1.57	0.00	1.57	3.14
	2	0.28	0.00	1.00	1.28
	3	0.85	0.00	0.71	1.56
737	1	16.41	2.00	3.00	21.41
	2	20.44	2.86	3.00	26.30
	3	5.00	1.00	0.00	6.00
737300	1	9.42	2.00	0.00	11.42
	2	5.86	0.00	1.00	6.86
	3	5.00	0.00	1.00	6.00
737400	2	1.00	1.00	0.00	2.00
737500	2	5.00	0.00	0.00	5.00
747200	2	0.28	0.00	0.14	0.42
	6	0.15	0.00	0.15	0.30
74720B	1	0.86	0.00	0.00	0.86
	6	0.00	0.86	0.00	0.86
757PW	1	8.86	0.14	1.00	10.00
	2	25.56	2.86	1.00	29.42
	3	48.29	2.86	3.00	54.15
	4	2.00	0.00	0.00	2.00
757RR	1	0.00	0.00	0.14	0.14
	2	0.43	0.57	0.00	1.00
	3	0.43	0.00	0.00	0.43
767300	2	6.86	1.28	0.00	8.14
	3	1.00	0.00	0.00	1.00
	6	3.00	0.00	0.00	3.00
767JT9	1	1.00	0.00	0.00	1.00
	2	2.43	1.86	0.00	4.29
	3	2.86	1.00	0.00	3.86
A320	2	1.00	0.00	0.00	1.00
BAE146	2	0.57	0.00	0.00	0.57

APPENDIX C
SUMMARY OF AIRCRAFT DEPARTURES AT DFW AIRPORT

AIRCRAFT	STAGE	DAY	EVENING	NIGHT	TOTAL
DC1030	1	0.00	1.00	0.00	1.00
	2	2.00	0.00	0.00	2.00
	3	5.00	0.00	0.00	5.00
	4	1.00	0.00	0.00	1.00
	5	2.00	0.00	0.00	2.00
	6	1.00	0.00	0.00	1.00
DC860	1	0.71	0.00	0.57	1.28
	2	3.59	0.00	3.57	7.16
	3	2.00	0.00	0.71	2.71
DC910	1	2.00	0.86	0.00	2.86
	2	7.30	0.00	0.00	7.30
DC930	1	14.58	0.86	0.00	15.44
	2	8.01	0.72	0.00	8.73
DHC6	1	31.59	7.58	3.44	42.61
DHC7	1	1.00	0.00	0.00	1.00
DHC8	1	82.02	14.86	7.44	104.32
F10062	1	28.00	3.00	4.00	35.00
	2	26.86	3.00	0.00	29.86
L1011	2	6.29	0.86	0.00	7.15
	3	1.00	1.00	0.00	2.00
L10115	2	0.85	0.00	0.00	0.85
	5	5.82	0.00	0.00	5.82
MD11GE	2	2.42	0.00	0.00	2.42
	3	1.00	0.00	0.00	1.00
	6	2.00	0.00	0.00	2.00
	7	4.00	0.00	0.00	4.00
MD11PW	1	0.00	0.00	0.72	0.72
	2	0.86	0.00	0.86	1.72
	3	0.85	0.00	0.85	1.70
MD83	1	65.86	12.00	9.00	86.86
	2	133.03	29.86	7.00	169.89
	3	89.00	15.58	2.00	106.58
SD330	1	28.17	9.02	1.00	38.19
SF340	1	95.30	12.00	12.72	120.02

APPENDIX D
EXAMPLE GIS DOCUMENTATION

Suggested working flow for developing a GIS with existing graphics and no database: [17]

I. Preliminary Steps:

  1. Install Oracle.
  2. Install MicroStation PC.
  3. Install MGE PC-1.
  4. Plan the Project.
  5. Get into MGE PC-1.

II. Set up the Project:

  1. Create the Project.
  2. Create a User with a password and privileges in Oracle.
  3. Create database schema.
  4. Define project schema (associate schema with project).
  5. Create categories and indexes; link categories to indexes (Category builder).
  6. Create and define features; link features to categories.
  7. Create user-defined attribute tables; link attributes to features.

III. Add Graphic Data to Project:

  1. Set up seed file; define coordinate system.
  2. Move graphics to "project\dgn" directory.
  3. Make features from graphic elements.

IV. Ensure Data Integrity:

  1. Thin vertices in densely digitized linework. (Line Weeder)
  2. Clean up intersections and free endpoints. (Line Cleaner)

V. Load the Database:

  1. Load the blank records. (Feature Maker -optional)
  2. Load area and perimeter values in database. (Area Loader -optional)
  3. Load graphic text into the database. (Label Loader -optional)

VI. Verify and Update Project Data:

  1. Verify feature definitions.
  2. Verify attribute definitions.
  3. Update attribute values.
  4. Load Map IDs for features. (Map ID Loader -optional)

VII. Access Project Data:

  1. Create geographic indexes. (Index Builder -optional)
  2. Create a vicinity map.
  3. Locate non graphic data.
  4. Locate graphic data.
  5. Change the active map.
  6. Select features to be displayed.

APPENDIX A

Page 1 of 9

QUALITY AND ACCURACY REPORT

DISCIPLINE ______
CATEGORY ______
THEMATIC LAYER ______
THEMATIC LAYER DESCRIPTION ______

EXTENT OF COVERAGE
STATE ______
COUNTY ______
APPRAISAL DISTRICT ______
SCHOOL DISTRICT ______
CITY JURISDICTION Robert Mueller Municipal Airport, Austin, Texas
OTHER ______

REPORT PREPARED BY Michael T. McNerney, P.E.

WHAT SOFTWARE DO YOU USE? MGE PC-1 / Microstation PC VERSION 1.2 / 4.0.3

ORGANIZATION The University of Texas at Austin

DIVISION Center for Transportation Research

SECTION Aviation Research

PHONE (512) 472-8875 FAX (512) 480-0235

DATE OF REPORT ______

DATA STRUCTURE (Circle One) [✓ VECTOR] RASTER

FILE TYPE (Circle One) [✓ GIS] CAD
Also CAD

I. LINEAGE

A. Description of source material(s)

1. Number of sources for this thematic layer: One

2. Source: City of Austin AutoCAD Drawing #023-25 dated 9/30/92

If there are multiple sources for this thematic layer, please complete this section for each additional source. (Duplicate section "A. Description of source material(s)" as required)

a. Describe geographic extent for the source: **(i.e. top 2/3's of digital map OR upper right quarter of digital map)**
entire area

b. Scale: **(ratio)** 1:1200 1:2400 [✓ 1:4800] 1:12000 1:24000 other 1:______

c. Datum: **(circle one)** NAD 27 NAD 83 Unknown

d. Geographical coordinates: **(the set of numerical quantities that designate position on the earth's surface)**

Lat, Long: X Extent: 2 positions, ll 30° 17' 27" 97° 42' 29"
ur 30° 18' 17" 97° 41' 41"

GRS 80: ____ Extent: 2 positions, ll ______
ur ______

WGS 72: ____ Extent: 2 positions, ll ______
ur ______

Clarke 1866: ____ Extent: 2 positions, ll ______
ur ______

Other ______

e. Map projection:

X No Projection

____ Lambert Conformal Conic (ie. State Plane-Texas North Central Zone), Zone: ______

____ Universal Transverse Mercator, Zone: ______

____ Albers Equal-Area Conic

____ Polyconic

____ Other: ______

f. Data lineage - data provided by: (circle all that apply)

[✓ field survey] visual flyover plat [✓ digital] quad

other AutoCAD Drawing

g. Remote Sensing primary source:

Platform: Aircraft Almaz Apollo Gemini

Landsat (ERTS): 1 2 3 4 5 6 7

Skylab Space Shuttle (U.S.) SPOT

Other: ____________________

Mission, System or Project Number:

Sensor: Camera MSS RBV TM ETM AVHRR RADAR

Other: ____________________

Spectral Mode: Color Color-IR

Black & White Multispectral

Spectral Bands: LANDSAT: MSS 1 2 3 4 5 6 7

False-color IR composite

SPOT: 1 2 3

Radar: X C L

Other: ______________ N/A

Orientation: Vertical Low Oblique High Oblique

Beam Polarization (radar): HH VV HV VH

Aperture (radar): Real Synthetic Both N/A

Look Directions (obliques): N S E W NW NE SE SW Unknown

Flight height (aircraft): ______________ Unknown

Focal Length (camera): ______________ Unknown

Average Scale (ratio): 1:__________

Format (size of images): ______________ N/A

Media: Digital Paper print Film negative Film positive Other ________

Cloud cover (range): ____-____% N/A

Viewing: Monoscopic Stereoscopic

Dates (month/day/year): __/__/__ Unknown

Scene, roll/frame, strip, or mosaic numbers (optional): ______

h. Source media: (circle all that apply) vellum mylar paper map blueprint/reproduction other Digital - AutoCAD

i. Age of source media: ______

j. Condition of media: (check one)

X excellent ___ above average ___ average

___ below average ___ poor

k. Creator of source material: (surveyor, engineer or draftsman,etc.)

Name Martinez and Wright Engineers, Inc.

Address 1105 Clayton Towers, Austin, Texas

Phone ( )______

l. Date of source material:

Time interval covered 9/27/89

Update schedule 10/30/92

3. Additional information Provided by City of Austin by Ron Gentry.

B. Derivation methods for data

1. Method of derivation: (The purpose of this step is to describe how the data was brought into the system.)

a. Preautomation compilation - description ______

b. Automation Equipment

Model ______

Resolution ______

Tolerance of Digitizer - (if digitized) ______

2. Date of automation:

   a. Initial date 4/93

   b. Update Schedule None

3. Control points:

   a. Surface coordinates to State plane grid "SCALE FACTOR": ____

   b. Rotation factor from true north to State plane: ____

   c. Azimuth: **Setup point:** ____, ____

      Azimuth point: ____, ____

      Angle to true north:(+ or -)__deg.__min.__sec.

   d. Type of structure/monumentation: ____

   e. Coordinate system: Latitude and Longitude

   f. Number of points in control network: Six

   g. Distribution of points: (What percentage of the points are located in which portions of the geographic extent) ____

   h. Accuracy of control point network: (e.g., 1st order, I) ____

   i. Coordinate reference system:

      X **No projection**

      ____ **State Plane - zone** ____

      ____ **Other -** ____

   j. List of control points and coordinate pairs: (attach list)

      Point # ____ **X =** ____, **Y =** ____

4. Hardware and operating system platform used:
   ACTAR 486/33 PC Compatible DOS 5.0

5. Software system(s) and version(s) used to develope digital data set:
   Microstation PC-4.0.3 with NEXUS

6. Explanation of procedures used to digitize/scan/transform, etc., data (Describe

the user created transformations that would indicate the Q/A of the data captured)

a. Name of transformation methodology DWGIN Utility

b. Description of algorithm

c. Mathematics used in the transformation

d. Set of sample computations Log file available

II. POSITIONAL ACCURACY

A. Feature (point, line and polygon) completeness check - How much of the original source information is represented in the digital data set.

1. Value: (what percentage of the linework found on the original was captured?)
2. Date of checks: (month/day/year)___/___/___
3. Method used to derive above value:

B. Feature (point, line and polygon) positional absolute accuracy check - Measure of error between a feature's digital coordinates and that feature's real world coordinates on earth, in units of coordinate system.

1. Value:
2. Date of checks: (month/day/year)___/___/___
3. Method of derivation of that number:

C. Feature (point, line and polygon) relative accuracy check- Measure of error between two features' digital relationship and those features' real world relationship on earth.

1. Value:
2. Date of checks: (month/day/year)___/___/___
3. Method of derivation of that number:

III. ATTRIBUTE ACCURACY -- DEMONSTRATION DATA ONLY

A. Quantitative attributes - If attributes are quantitative/numeric in nature, answer the following 2 questions, otherwise, skip them and go on to B.

1. Completeness check: Has there been a random check to determine whether all quantities/numbers on the source material were added? Yes ____ No ____
    a. Value: It is estimated that _____% of all quantities/numbers on the source material were captured.
    b. Date of checks: (month/day/year)___/___/___
    c. Method used to derive value: ______________________________

    ____

2. Quantity/Number accuracy check: Has there been a random check to determine whether quantities/numbers on the digital product are correct? Yes ____ No ____
    a. Value: It is estimated that _______% of all quantities/numbers on the digital product are correct.
    b. Date of checks: (month/day/year)___/___/___
    c. Method used to derive value: ______________________________

    ____

B. Non-quantitative attributes - If attributes are non-quantitative/non-numeric (i.e., feature types, feature names, etc.) answer the following.

1. Completeness check: Has there been a random check to determine whether all attributes were added? Yes____ No____
    a. Value: It is estimated that ______% of all attributes on the source material were captured accurately.
    b. Date of checks: (month/day/year)___/___/___
    c. Method used to derive value: ______________________________

    ____

IV. LOGICAL CONSISTENCY (for Vector Data only)

A. Cartographic tests

1. Answer the following:
    a. Do lines intersect only where intended? (Yes/No/Unknown)

Page 8 of 9

b. Were duplicate lines eliminated? ([✓ Yes]/No/Unknown)

c. Are all areas completely described? (Yes/[✓ No]/Unknown)

d. Have overshoots and undershoots been eliminated? ([✓ Yes]/No/Unknown)

e. Have all slivers been eliminated? ([✓ Yes]/No/Unknown)

f. Does documentation in the lineage section describe why the data is cartographically clean? (Yes/[✓ No]/Unknown)

g. Does the provider feel the map is cartographically clean? (Yes/[✓ No]/Unknown)

2. Tests

a. Test(s) performed ______________________________

____

b. Date(s) of test(s) ____________________

B. Topological tests

1. Tests

a. Test(s) performed ______________________________

____

b. Date(s) of test(s) ____________________

c. Does topology exist? ([✓ Yes]/No)

d. Software and version used MGE-PC-1 1.2

2. Results

a. Tests for polygon coverage

i. How many polygons are represented on the digital map product? 129

ii. Has a polygon closure been verified? ([✓ Yes]/No/Unknown)

iii. Are polygon-ids assigned to each polygon on the digital map? ([✓ Yes]/No/Unknown)

iv. Do polygons have more than one polygon-id? (Yes/[✓ No]/Unknown)

v. Are the polygon-ids unique? ([✓ Yes]/No/Unknown)

b. Tests for line coverage

i. How many lines are represented on the digital map product? Many

ii. Do the line segments have unique line segment values? (Yes/[✓ No]/Unknown)

c. Tests for point coverage

i. How many points are represented on the digital map product? ______

ii. Do the points have unique point values? (Yes/[✓ No]/Unknown)

V. COMPLETENESS OF SOURCE MATERIALS

A. Selection criteria (which features were captured and what was the criteria for selecting those features?)

B. Definitions used ______

C. Relevant mapping rules (guidelines used by persons who developed this digital data set)

D. Deviation from mapping rules ______

E. Test for taxonomic completeness (do the feature sets included in the digital data set represent a complete range of possible features?)

1. Procedures ______

2. Results ______

VI. DISCLAIMER FROM DIGITAL DATA CUSTODIAN

Data used for demonstration purposes only. No warranties or claims concerning the accuracy of the map or data are made.

APPENDIX B-1

Page__of__

DATA DICTIONARY
THEMATIC LAYER SUMMARY

DISCIPLINE: AIRPORT ENGINEERING AND MANAGEMENT
.TEGORY: (Manmade, IDX) PAVEMENT
THEMATIC LAYER: RUNWAY

Report Prepared By: MICHAEL T. MCNERNEY
Organization: The University of Texas at Austin
Division/Section: Center for Transportation Research

Phone: (512) 472-8875 Fax: (512) 480-0235 Date of Report: 5/9/93

Thematic Layer	Entity Types	Associated Attributes
Runway	Area boundary	Table runway
		Branch
		family
		r_section
		PCI current
		pave_type
		repair yr
		r_traffic
		r_id
	Area centroid	"
		"
		"
		"
		"
		"
		"
		"
		"

APPENDIX B-2

Page 1 of 2

DATA DICTIONARY
ENTITY REPORT

DISCIPLINE: AIRPORT ENGINEERING AND MANAGEMENT
CATEGORY: PAVEMENT Manmade.idx
THEMATIC LAYER: RUNWAY
ENTITY TYPE: Area Boundary

Report Prepared By: Michael T. McNerney
Organization: The University of Texas at Austin
Division/Section: Center for Transportation Research

Phone: (512) 472-8875 Fax: (512) 480-0235 Date of Report: 5/9/93

I. **Entity Label** - Digital file name of the entity.

Map: Site 3. dgn
feature name: runway
feature number: 2000

II. **Entity Definition** - Common name and description of the entity.

runway sections - usually 50 x 200' ft sections
r_id=
branch BR
family A,B,C
section 1-37

III. **Entity Authority** - Organization and/or document through which a meaning is assigned to an entity label. Usually the agency charged with creating, coordinating, or maintaining a thematic layer.

branch 13R, 13L, or 17
family A,B,C
section 1-37
r_id= for example 13RA37

IV. **Quantity of Data** - Number of records or entries, including geographic extent.

111 Area defined by approximately 270 Arcs

APPENDIX B-4 Page 1 of 2

DATA DICTIONARY
ATTRIBUTE REPORT

DISCIPLINE: AIRPORT ENGINEERING AND MANAGEMENT
CATEGORY: PAVEMENT (manmade.idx)
THEMATIC LAYER: Runway
ENTITY TYPE: Area boundary
ASSOCIATED ATTRIBUTE: runway

Report Prepared By: Michael T. McNerney
Organization: The University of Texas at Austin
Division/Section: Center for Transportation Research

Phone: (512) 472-8875 Fax: (512) 480-0235 Date of Report: 5/9/93

I. **Attribute Label** - Digital file name of a defined characteristic of the entity.

runway

II. **Attribute Definition**

A. Description - Common name and definition of the attribute.

runway section of pavement

B. Measurement Determination - What the attribute is based on and how the data were determined.

To follow the definitions in the MicroPAVER Guide. Each area of the runway sections are identified by branch, family, and section

Page 2 of 2

III. Attribute Authority - Organization and/or document through which a meaning is assigned to the attribute label.

branch=runway ie 13R
family=A(left 3rd), B(center third), C(right third)
section=#1-37 #1 at 13R threshold
each 50 x 200' in area until the end section

IV. Domain Value

A. Data format - The format that the attribute value can take. One of six types indicating the manner in which the field or subfield is encoded:

___ A Graphics, alphanumeric, or alphabetic characters (circle one)

___ I Implicit-point (integer; e.g., 12)

___ R Explicit-point unscaled (real; e.g., 12.3)

___ S Explicit-point scaled (real with exponent; e.g., 12.3 x 10^3)

___ B Bit field data (unsigned binary, per agreement)

___ C Character mode bitfield (binary in 0 and 1 characters)

B. Length - Number of spaces in attribute field in which to encode data (as appearing in formatted output; e.g., 5 spaces in the case of 12.39).

____

C. Number of significant digits (numbers to the right of the decimal).

____

D. Units of measurement

____