NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **326**

DEVELOPMENT OF A ROADWAY DESIGN/GRAPHICS INTERFACE SYSTEM

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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REPORT 326

DEVELOPMENT OF A ROADWAY DESIGN/GRAPHICS INTERFACE SYSTEM

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST

Facilities Design
(Highway Transportation)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D. C.

JUNE 1990

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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FOREWORD

By Staff
Transportation Research Board

The primary objective of the research documented in this report was to design a standard file for the exchange of computerized roadway design and graphics data. A standard file, if adopted and maintained, would have the potential of facilitating the transfer of data between existing, but different, systems and for providing a target for future software program developments. Based on a thorough investigation of DOT needs, systems used, and interchange formats, a specification was defined for a standard file format, the Common Data Interchange File (CDIF), that could accommodate interrelated roadway design and graphics data. Prototype software for data-interchange processes was also developed for the more commonly used state DOT systems to demonstrate the utility of the interface. Accordingly, the research results will be of interest to those individuals involved in the design of highway facilities and to software and hardware developers who are confronted with the need to exchange data produced with computer-aided design and drafting systems. Communications regarding use of the CDIF have occurred with the American Association of State Highway and Transportation Officials (AASHTO). As a result, the CDIF concept is presently being employed by the Joint Development Task Force of AASHTO's Administrative Subcommittee on Information Systems to allow vendors an opportunity to interface with AASHTOWARE™ computer roadway design and graphics software.

More and more state departments of transportation are relying on computer-aided design and drafting (CADD) systems to help them prepare and produce their roadway designs. The procurement and implementation of such systems do not usually occur at one time throughout all departments. Consequently, state DOTs may acquire a variety of systems over time, or they may wish to continue to take advantage of new technologies as they evolve. State DOTs also contract design work to consultants who may or may not have compatible systems. This array of possible situations highlights the potential problem of exchanging graphic and design data among various systems. Inadequate capability for such exchanges hinders productivity, limits competition, and inhibits the advantageous use of new developments in hardware and software.

As a means to enhance data exchange, C. W. Beilfuss & Associates was assigned NCHRP Project 15-10, "Development of a Design/Graphics Interface System," to develop a standard file specification for the exchange of roadway design and graphics data produced by various computerized systems and to demonstrate the utility of the standard with actual data transfers. A specified standard file, the Common Data Interchange File (CDIF), was developed. The AASHTO Administrative Subcommittee on Information Systems, through its Joint Development Task Force, is already using the file format as an initial "target-file" for outside vendors and software developers to communicate with the AASHTOWARE™ roadway design systems.

The research agency also demonstrated, to a limited extent, the actual exchange of information. The computer programs employed for this purpose are available for use and further development. All of the software was developed in FORTRAN for a DEC VAX environment. The descriptions are written using DEC VAX terminology and descriptive notations. The FORTRAN source code, executables, and test data are available for DEC VAX computer systems on a single magnetic tape (9 track, 1600 BPI, 1200 foot reel). Those wanting a copy should send a blank magnetic tape to the Transportation Research Board, *ATTN:* NCHRP Project 15-10, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

However, prior to obtaining the magnetic tape, familiarization with the information contained in the appendixes (A through E) of the agency research report is recommended. The appendixes to the agency's final report are not published herein, but copies of that report, entitled "Development of a Design/Graphic Interface System—Appendixes A-E," will be transmitted to all state DOTs addressed specifically to the membership of the AASHTO Administrative Subcommittee on Information Systems. Others may obtain copies on loan or for purchase ($15.00) by writing to the previously noted address for the Transportation Research Board. The available appendixes are titled as follows: Appendix A, Guidelines for Entry of Data to be Transferred; Appendix B, Common Data Interchange File Specification; Appendix C, Information for DIP Usage; Appendix D, Programmer Information for DIP Enhancement/New Development; and Appendix E, Test Data. Note, also, that because of the potential for continued updates and modifications, for example, by AASHTO, the agency copy of the appendixes has been predrilled so that it can be placed in a loose-leaf notebook.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP 15-10 by C.W. Beilfuss & Associates, Inc. The work was a compilation of efforts by several data processing, systems and engineering professionals responsible to the principal investigators for the major topics of research.

Charles W. Beilfuss, President of the organization, was the Principal Investigator for the Engineering Research considerations and was responsible for the development of the roadway design data portion of this report. Assisting Mr. Beilfuss in the roadway design data activities was Mr. Ronald A. Love, Engineering Analyst, who was chiefly responsible for the development of the roadway design data specification and prototype data interchange process software. Assisting Mr. Love in the software development were Mr. Thomas P. Mettel and Mr. Peter W. Lee.

Roy R. Guess, Manager, Senior Consultant, Regional Office, Houston, Texas, was the Project Manager and Principal Investigator for the Technical Research considerations and was responsible for the development of the graphics data portion of this report. Assisting Mr. Guess in the graphics data activities were Mr. Edwin C. Bain, Lead Systems Analyst, Mr. Patrick C. Achterberg, Systems Analyst, of the Regional Office, Houston, Texas, and Mr. Naimish S. Shah, Lead Systems Analyst, Corporate Office. Mr. Achterberg was chiefly responsible for the development of the prototype graphics data interchange process software.

Much appreciated assistance was provided by Mr. Charles Gebhardt and others of the Ohio Department of Transportation in the software testing process.

DEVELOPMENT OF A ROADWAY DESIGN/GRAPHICS INTERFACE SYSTEM

SUMMARY

Over the past decade, state departments of transportation have experienced a rapid evolution of their procedures for designing highways and bridges. This evolution has been created by changes in computer technology. Many DOTs have experienced (1) migration from their own roadway design system to a vendor or cooperatively supported roadway design system; (2) use of one or more of the following systems (Interactive Graphics Roadway Design System (IGrds), interactive graphic drafting systems for producing highway and bridge plan sheets, minicomputers and microcomputers instead of, or in addition to, mainframe computers for design, construction, management, and maintenance); and (3) increased use of consultants with various systems for highway design and construction engineering.

Although these new procedures and automated tools have dramatically increased employee productivity, they have also created serious problems concerning how to effectively transfer information (both design and graphic) between these various computer systems or their users.

Since the late 1970s, there have been numerous efforts to create an effective means to exchange graphics data between drafting systems. No known efforts have been instituted to exchange roadway design data. To date, attempts to achieve graphics data interchange have not been completely successful because of problems attendant with the broad scope of the standard file specifications and limited understanding of both sending and receiving systems on the part of users. The need for an effective solution to these problems provided the primary impetus for the establishment of this research project.

The basic objective of NCHRP Project 15-10 was to design and develop a nonproprietary data interface between transportation agency computer roadway design systems and generally used interactive computer graphics drafting systems. In particular, the interface was to include the transfer of roadway design data, transportation-related graphics data, and interrelated design and graphics data. The user community served by this data interface includes the following entities: departments of transportation (DOTs), DOT consulting contractors, and other transportation-related agencies and organizations.

The general approach to develop the interface was to prepare a specification for a "neutral" file, or common data interchange file (i.e., CDIF) format, that allowed for the exchange of design/graphics data between different computer systems. Data interchange processes (i.e., computer programs referred to as DIPs) were developed to transfer data between the most prevalent design and graphics systems and the CDIF format, to demonstrate the feasibility and practicality of the interface system. In addition, these prototype DIPs serve as the basic foundation for further software development in the future, and provide as well several useful (although currently somewhat limited) software tools for interchanging data between the systems selected for the demonstration.

Figure I graphically depicts the various components of the data interface system.

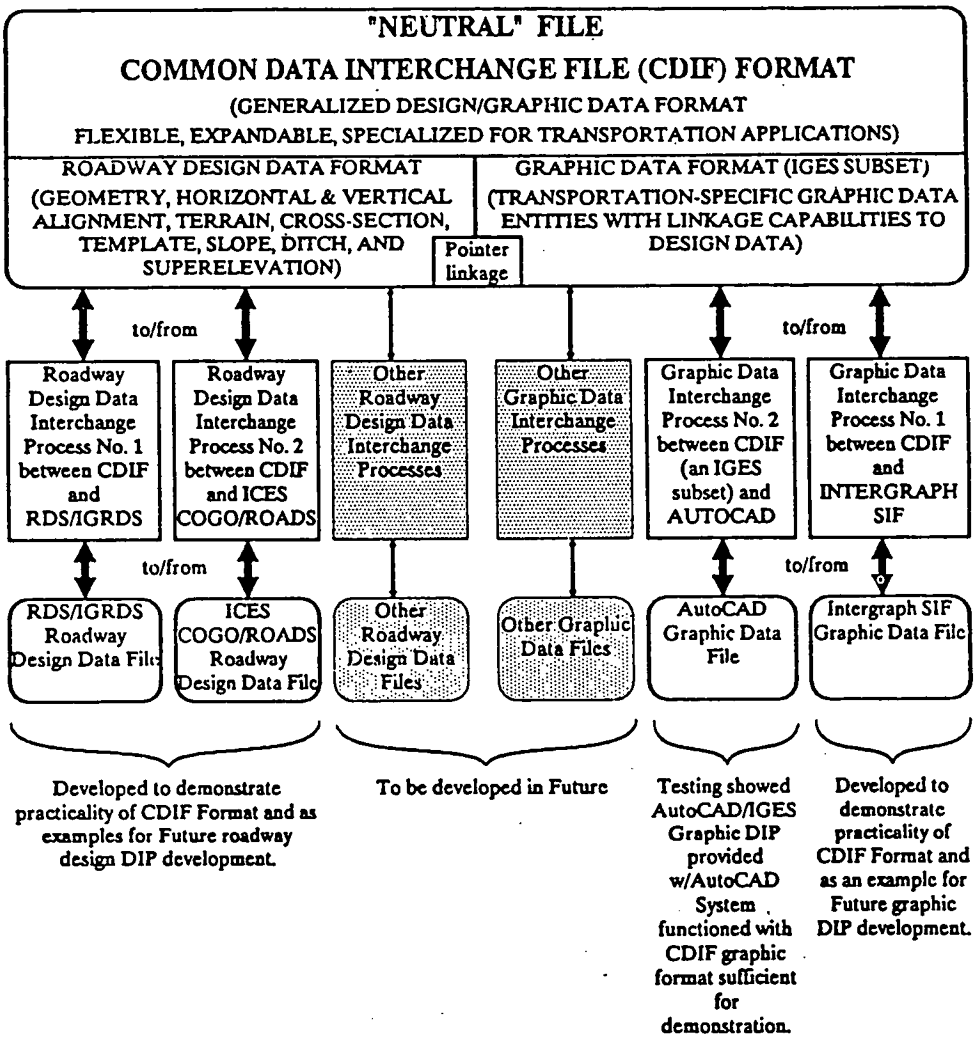

Figure I. Roadway design/graphics data interface.

The figure identifies the general concepts used in the development and the general types of data included in the interface. It also identifies the specific roadway design and graphics data file formats that were used in the development and are currently supported by the interface system. The bidirectional (to/from) flow of data between the various file formats are also shown.

The development of the interface was accomplished using a phased implementation plan where information was collected and analyzed from DOTs and system vendors, a general and detailed design was prepared, and the CDIF format specification and prototype DIP software were developed.

The basic concept used to guide the overall design of the interface was to increase the likelihood of successful data transfer by limiting the scope of the data to encompass only elements that were essential for the roadway processes and to emphasize these data transfer limitations to the users. The CDIF format was designed to be as simple, flexible and expandable as possible, and be structured to provide adequate pointer/ linkage mechanisms to relate graphics elements and their respective roadway design data.

The national standard Initial Graphics Exchange Specification (IGES) data interchange format was used to provide the basic structure for the CDIF format. The CDIF graphics data format was patterned exactly after the IGES format for those graphics elements required by DOT applications. The CDIF roadway design data format was not able to directly utilize the IGES format because of the different data requirements. However, the IGES general structure and pointer mechanisms were applicable to the needs of the design data and, therefore, the overall structure and mechanisms could be used in the design of the roadway design data structure.

The general types of data in the CDIF specification for roadway design included geometry, horizontal alignment, vertical alignment, terrain, cross section, template, slope, ditch, and superelevation. The graphics data elements in the CDIF specification generally included all point and linear graphics elements, textual, symbol, font, and data grouping entities used in normal transportation applications.

The systems (or data file formats) selected as most appropriate for demonstrating the practicality of the CDIF specification were:

- For roadway design—RDS/IGrds and ICES COGO/ROADS
- For graphics—Intergraph (SIF) and AutoCAD

Data interchange processes were developed for each of the systems/formats (except AutoCAD which already provided an IGES data transfer process with the graphics system that was tested and found to be sufficient for demonstration of the CDIF graphic format). The DIP software processes convert data between (to/from) the CDIF format and each of the selected formats. The processes were tested at the contractor site, as well as remotely at a DOT site (Ohio), with DOT-related test data sets designed to thoroughly exercise the CDIF specification. Examples of test data have been included on magnetic tape, along with the DIP source code, to assist users in understanding and becoming familiar with the CDIF interface. DOT data acquisition guidelines, DIP user's instructions, the CDIF format specification, and programmer's technical guidelines were prepared and are included in the appendixes of this report.

The software developed under this project includes approximately 260 routines to perform the data transfers currently being supported. The software was designed and written in a modular fashion to allow maximum flexibility and use in the development of new data transfer processes (for other design/graphics systems) in the future. A great many of the current routines, which are utility routines, compose a "tool kit" that should provide substantial assistance for future DIP development. Because of project constraints, the prototype DIP software developed for demonstration purposes was, in some cases, limited in the variety of data transfer paths and data element types supported and in the complexity of the user interface. The prototype DIP software adequately demonstrates the feasibility and practicality of the CDIF interface and provides appropriate examples (and utilities) for future development of other DIPs. However, before the prototype DIP software can be put into general use for the transfer of design and graphics data, the software must be expanded to support more data transfer pathways, to include a broader range of data element types, and to improve the friendliness of the user interface.

The CDIF specification must continue to evolve after this project, with additions, modifications, and other improvements being identified through ongoing beta testing and production use. In order to fulfill this requirement, a single dedicated clearing house for support should be identified so that updates proposed to the Common Data Interchange File (CDIF) can be implemented in a controlled manner and the standard can be promulgated.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

BACKGROUND AND PROBLEM

Since the birth of computerized roadway design systems around 1956, these systems have become increasingly more prevalent, in various forms and with ever increasing capabilities, for use by all practitioners of transportation engineering design. Since the early 1960s, computer graphics technology has been used, where practical, to assist in the communications between the user and these roadway design application programs. However, it was not until the middle to late 1970s, with the introduction of cost-effective integrated computer graphics for automating drafting functions, that the roadway design applications were able to begin to take full advantage of the computer graphics technology. The interactive graphics drafting systems (referred to in this report as IG drafting systems) provided much needed tools in the automated production of plan sheets and showed great promise for assistance with the roadway design process.

In the early 1980s, national interest in revitalizing public works in this country began to increase, especially as they were related to highways. The need for generally improved engineering productivity, the appropriation of new highway rehabilitation and rebuilding resources, and the availability of increased engineering productivity as a result of the advancement in the computer-aided design and drafting technology all combined together to provide the stimuli for integrating roadway design systems with IG drafting systems to serve transportation engineering design applications. The Interactive Graphics roadway design system (IGrds) is one example of the type of processes that have recently been produced to accommodate DOT application needs.

These same stimuli and the availability of the cost-saving software processes provided the motivation and justification for a significant increase in the use of computers in design and drafting throughout the many elements of transportation engineering. In addition to this increased use, there was also an associated increase in the numbers and variety of systems available. For the graphics systems, there was a clear need to develop avenues for the transfer of graphics files developed on one IG drafting system to another. Substantial and effective movements were begun by the airframe industry to develop specifications for standard graphics data exchange (Initial Graphics Exchange Specification, IGES). Although IGES provided a good foundation for the exchange of graphics data for mechanical design applications, it proved to be somewhat complex and cumbersome to use for normal transportation applications.

The difficulties encountered in the exchange of data between graphics systems, prior to the development of the exchange standards, at present have their counterpart in the exchange of data between roadway design systems, such as ICES/ROADS, RDS/IGrds, UNMES, and others. (In this report, the term "design systems" will include both the traditional form of roadway design systems and interactive graphics roadway design systems.) Although the technology of the traditional design systems has been in use longer than has that of interactive graphics, little, if any, progress has been made to create automated interfaces for them. In the past, the need for exchange of data between design systems was less because, in most cases, the data were converted into design drawings which became the media to transfer the design results. Now that the transference of the design drawings in computer readable form, and the transfer of data between traditional design and IG drafting systems, is a real possibility, the value of transferring computer readable data between design systems of all types takes on greater importance.

It became more apparent, as DOTs began to depend on data from design systems and IG drafting systems, that they would benefit not only by using these procedures themselves, but that they would benefit also from the use of these same systems by their design consultants. However, if such systems are used in the consultants' subcontract design services for a DOT, the Department should receive the design and drafting data in computer readable form so that it can be processed by the Department to check the results and to update the design and/or drafting data in the future. Although problems arise in interpreting data when the DOT's graphics and/or design systems differ from those of their consultants, DOTs must be careful not to restrict the consulting work to those organizations that have acquired the same kinds of equipment and software that have been selected by the Department. To assure that restrictions such as these do not eliminate bonafide organizations from performing work for the Departments, there should be available the means to transfer data between different design and drafting systems with as few restrictions as possible.

This same data transfer need also exists for many of the DOTs where various units or divisions within a single organization may use different hardware and/or software to perform various portions of the road design process, or where hardware and software may change in a DOT between the completion of the original design and the time when rehabilitation is required.

Figure 1 graphically identifies the various conditions for data exchange. This figure depicts the requirements for passing design and graphics data between various units or organizations that are involved in the design of roadways. The needs to be served by Project 15-10 are to automate these data transfers and, thereby, eliminate the requirement for extensive hand processing.

PROJECT OBJECTIVES

The basic objective of this research project was to design and develop a nonproprietary data interface between transportation agency computer roadway design systems and generally used interactive computer graphics systems. In particular, the interface was to include the transfer of the following data: roadway

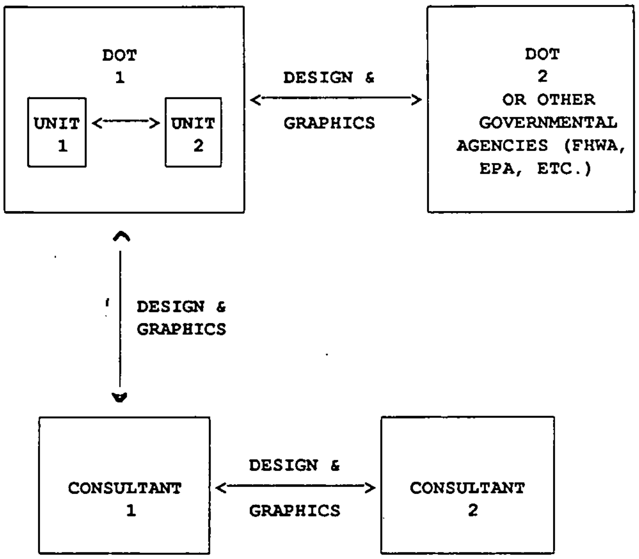

Figure 1. Organizational data transfer needs.

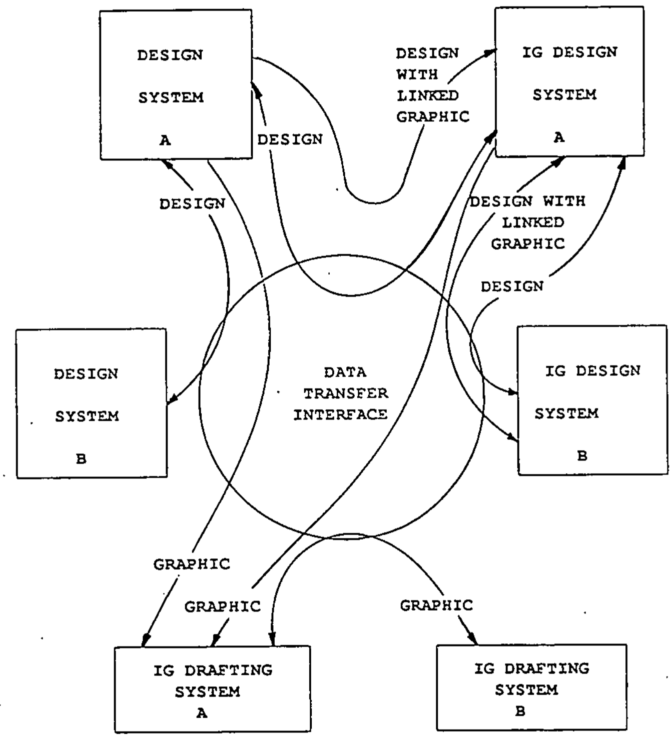

Figure 2. Data transfer interface requirements.

design data, transportation-related graphics data, and interrelated design and graphics data.

The data will be transferred in a variety of ways between the roadway design systems and interactive graphics systems. The user community to be served by this data interface includes the departments of transportation (DOTs), DOT consulting contractors, and other transportation-related agencies and organizations. Figure 2 graphically depicts all of the various data pathways, types of systems, and varieties of data that must be supported by the data interface.

RESEARCH APPROACH

The general approach that was taken to develop the data interface encompassed several key concepts: the specification of a "neutral" file format, and the implementation of computer processes to transfer the required data in a particular manner.

A primary concern of any data exchange process between various different types of systems is the specification of a "neutral" file format, which is used to hold the data to be transferred in a form that is most appropriate for maintaining the intelligence of the original data and providing the easiest data conversion for all systems/formats that are likely to be involved. For this project and report, this format was referred to as the Common Data Interchange File format, or CDIF format. The CDIF file was structured as one logical file containing two physical files, one for roadway design data and one for graphics data, with the ability, as needed, to relate these two types of data. The structure was designed to be as flexible and dynamic as possible to provide for easy expansion in the future. The scope of the CDIF format capabilities was directly related to the needs of data exchange for the types of systems used by transportation organizations.

The "national standard" Initial Graphics Exchange Specification (IGES) data interchange format was used to provide the basic structure for both the graphics and roadway design data formats in the CDIF file. For the graphics format, a simplified subset of the IGES data elements was sufficient to fulfill the transportation application graphics data needs. The roadway design data could benefit only from utilizing the overall file structure and some of the more general data record fields because the design data were so different in nature from the graphics data.

The Common Data Interchange File Format is described in detail in Chapters Three and Four and is represented in Appendix C by a detailed set of specifications that defines the format for the roadway design data, the graphics data, and how the two types can be interrelated within the CDIF format. The CDIF specifications are sufficient for use by a programmer desiring to create computer software to transfer data to/from a design or IG drafting system using the CDIF format. The specification provides a detailed-description of the formats of the CDIF record(s), record fields, record identifications, methods for arranging records within the CDIF, and the scheme for relating design and graphics data and/or records.

To transfer design and/or graphics data to and from the CDIF requires a process that was referred to as a "Data Interchange Process," or DIP. The term "process" indicated that one or more computer programs were required to perform the transfer and formatting of data between a system and the Common Data Interchange File.

Investigation of DOT applications and systems indicated that the RDS/IGrds and ICES/COGO/ROADS systems provided the best demonstration for the roadway design data portion of the CDIF format and that the Intergraph and AutoCAD systems provided the best demonstration for the graphics data portion of the CDIF format. "Prototype" DIPs were developed for these systems to demonstrate the feasibility and practicality of the interface system and to provide a foundation and examples for future DIP enhancement and development. To minimize the DIP development effort required, the graphics DIPs were, when practical, based on existing interchange software provided by system vendors for general graphics data interchange.

The Data Interchange Processes that were developed for this project are described in detail in Chapters Three and Four and are represented in Appendixes C, D, and E by detailed user, programmer, and testing information. The user information is sufficient for use by data processing users desiring to convert design or graphics data between any of the selected systems. The programmer information will assist a programmer in the creation of data transfer software. The test data information should assist anyone interested in understanding or using the DIP software.

The tasks that were required to be done with this general approach for the entire project can be summarized as follows:

- Perform extensive investigation of existing traditional roadway design systems, IG roadway design systems, IG drafting systems, graphics data interchange formats and specifications, and DOT data interchange needs.
- Prepare a general design report.
- Perform detailed design work and prepare a detailed design report.
- Implement specific interchange process software.
- Prepare appropriate software documentation and interface specifications included in a final report.

CHAPTER TWO

FINDINGS

QUESTIONNAIRE REVIEW

As part of the initial investigations, a questionnaire was prepared and sent out to all DOTs soliciting information to determine which computer hardware systems, roadway design systems, and IG drafting systems were being used or were being contemplated for use in state DOTs and what were the current data interchange needs in state DOTs.

The information received from the DOTs had a very significant impact on the design of the interface. The number of organizations employing each system pointed out where the greatest benefits were to be gained by the development of exchange capabilities. The structures of the more prevalent systems had a greater influence on the design of the interface than the less prevalent. Further, the manner in which each organization used the systems (e.g., more than one system in an organization, requiring consultants to transfer data in specific computer readable form, etc.) indicated how the interface process should be developed.

SUMMARY OF DOT STATISTICS

The overall response from the states was very good, with 40 states responding to the questionnaire. Additional information was also available from other sources.

The information received from the DOTs can be classified into three basic categories: (1) general information (existing or proposed hardware configuration and general interest in data transfer); design system usage, both traditional and IG and specific design data transfer needs/requirements; and (3) IG drafting system usage and specific graphics data transfer needs/requirements.

General Information

The vast majority of the states (40) dealt with IBM mainframes, of varying sizes, for handling most of the processing needs for roadway design. A large majority of the states (34) reported that they were currently (or would be) using the DEC VAX minicomputers to handle their interactive graphics and/or design processing needs. A relatively small number of the states (12) expressed interest in microcomputers to handle some of the design and/or graphics workload, but there has probably been a significant increase in this number more recently.

A large majority of the states (34) indicated that they had some level of interest in the transfer of data between various systems. This interest was divided between internal and external data transfer, with internal being primary.

Design Systems

A large majority of the states (30) reported that they were currently (or would be) using the Roadway Design System (RDS) and/or the Interactive Graphics Roadway Design System (IGrds). The next most widely used system was McAuto's ICES/COGO ROADS System with eight states using it. A number of states had an in-house developed design system, sometimes in addition to RDS or ICES. Many states also reported using various Coordinate Geometry Systems in addition to their design system's COGO process.

A relatively small number of states (7) expressed a current need to specify a particular form in which externally produced design information should be delivered to the DOT for their use. More recently, because of a variety of reasons, this number has likely grown substantially.

IG Drafting Systems

An overwhelming majority of the states (43) now have, will have, or were investigating the acquisition of an interactive graphic drafting system. A large majority of states (32) now use or will be using the Intergraph IG drafting system. The other states were dealing with assorted systems (e.g., Technicad, AutoCAD, Synercom, Diginetics, Autotrol).

About half of the reporting states (20) express some kind of need for transferring externally produced drafting data (e.g., plan sheets, maps) in a digital computer-readable form. A few of these states were specifying that graphics data be presented in a particular form (e.g., "Intergraph-compatible," SIF, IGES).

DESIGN/GRAPHICS DATA FOR DOT APPLICATIONS

Specific key data elements (both design and graphic) were selected to comprise a simplified set of criteria that was used as a basis of comparison for all of the various design and graphics systems investigated in this research. This was in keeping with the overall project objective to increase the likelihood of successful data transfer by limiting the scope of the data included in the interface to encompass only elements that were essential for DOT roadway design and graphics applications.

The comparison of the systems using the simplified criteria served two useful purposes: (1) to determine the overall compatibility of "transportation-specific" information between the various systems which indicated the easiest and best methods of data transfer between systems, and (2) to assure that the design of the "neutral" CDIF file was general enough to satisfy as many systems as possible for the simplified set of data.

Key Roadway Design Data Elements

The set of key roadway design data elements to be used for comparing the various design systems was defined as follows:

1. Geometry—defining points, lines, curves, courses, chains, distances, angles, and directions.
2. Horizontal Alignment—defining PI location radius of curvature, stationing, and equations.
3. Vertical Alignment—defining VPI location (station/elevation) and curve lengths.
4. Terrain Cross Section—defining top surface and subsurface.
5. As-Designed Cross Section—defining top surface, subsurface, and point attributes (i.e., crown, shoulder, catch).
6. Roadway Design Criteria—defining shape and/or location for typical cross section, template, slope, median, ditch, and superelevation data.

Various other types of less critical design data, such as area and volume data and digital terrain model data, were not necessary because, in some cases, they could be easily recomputed and, in other instances, the form of the data varied so greatly between systems that transfer was impractical.

Key Graphics Data Elements, Techniques, and Mechanisms

A set of key graphics data criteria was established for comparing all of the IG drafting systems, as well as the interchange formats. The criteria identified the graphics elements, the element grouping techniques, and other useful mechanisms that are necessary, or desirable, for handling the graphics data associated with DOT applications. The graphics elements selected included the following: (1) point, (2) line, (3) line series, (4) polygon, (5) spline curve, (6) circular arc, (7) circle, (8) elliptical arc, (9) ellipse, (10)parabola, (11) spiral, (12) text, and (13) symbol.

The element grouping techniques included: (1) linear elements (open), (2) linear elements (closed), (3) text group, and (4) grouping of all elements.

The other useful graphics data mechanisms that were applicable include: (1) use of attribute data attached to graphics; (2) availability of fonts for lines, text, and symbols; and (3) graphics data transformation (translation and rotation). Other more exotic special-purpose graphics elements and 3-D solid elements were not included for the sake of simplicity and because they were not critical to DOT applications.

SYSTEMS AND FORMATS INVESTIGATED

Information obtained from DOTs and other sources identified 15 roadway design systems, 15 IG drafting systems, and 4 graphics data interchange formats as candidates for investigation under this project. Documentation for some of the systems was not available, making investigations of those systems not possible.

Roadway Design Systems Investigated

The roadway design systems for which some documentation was available were organized into the following categories to facilitate comparison:

1. Broadly Used—ICES COGO/ROADS and RDS/IGrds.
2. Custom Developed and Individually Used—Minnesota, New York (CADRE), New Jersey (GEOGIFT), UNMES, Virginia, Washington, and Wisconsin.
3. Ground/Roadway Modeling (intended for broad use)—CARTA/TERRA, MOSS.
4. Commercially Developed, Low Cost—CIVIL SOFT, CLM COGO.

The design systems in the first two categories were similar in concept and design and operated in similar computer system environments. The primary difference between systems in the two categories was breadth of use. The "broadly used" systems provided substantial guidance in the development of the interface, whereas the "less used" systems were utilized to produce a more generalized design for the data interface file. Systems in the third category were found to be complementary to the other systems, rather than comparable. Documentation for systems in the last category was sparse or not available; however, it appears that the use of this type of system is becoming increasingly more widespread. Systems in the last two categories provided only minor input into the design and development of the interface.

Table 1 lists all the design systems recognized, the type of documentation available, and the level of review that was done for each system.

The design system comparisons related to the simplified data criteria revealed that none of the systems represented the "total system," of which all others are merely subsets. Each of the systems had some computational features, data categories, and data elements that were indeed unique to that system alone, thus making transfer of that type of data impossible. Finally, there were approximately 200 different data elements in a RDS storage file and more than 1,100 separate input data elements for the

Table 1. Investigation of design systems.

	Recognized	Reviewed Input	Reviewed Files
1. COGO - { McAuto	X	D	-
{ In-House (Wash. DOT)	X	D	-
{ In-House (Others)	X	-	-
{ CLM	X	C	-
2. ROADS	X	D	-
3. Virginia	X	D	-
4. Washington	X	D	-
5. Wisconsin	X	D	-
6. RDS	X	D	D
7. IGRDS	X	D	D
8. MOSS	X	C	-
9. UNMES - No Documentation	X	-	-
10. CIVIL SOFT	X	-	-

C = Cursory Review

D = Detailed Review

\- = No Information to Review

RDS system. This provided insight into the magnitude of the task for dealing with either of these types of data.

IG Drafting Systems Investigated

The IG drafting systems that were appropriate for meeting the DOT application needs fell into three basic system categories: (1) mainframe-based, (2) minicomputer-based, and (3) microcomputer-based.

Information was acquired concerning systems from each of these categories by sending a letter of request for documentation to all currently known system vendors. A total of nine systems were investigated, as noted in Table 2.

The investigation was limited to the graphics data elements, grouping, and other mechanisms identified as being associated with DOT applications. The following observations are noteworthy.

In general, all systems investigated dealt with graphics data elements required by DOT applications in a manner adequate for data transfer purposes. Spiral elements were the exception, but these elements could be adequately represented by alternative data elements.

The grouping of data was dealt with by all systems, in at least one manner, adequate for data transfer. The handling of fonts and attribute data was similar enough in a majority of the systems to support data transfer.

Graphics Data Interchange Formats Investigated

Several available graphics data interchange formats were investigated to determine their applicability as the basis for data exchange of DOT application data. Each of the formats was evaluated against the graphics exchange criteria cited earlier in this chapter. The formats evaluated were:

- Initial Graphics Exchange Specification (IGES—A national standard format developed for the airframe industry.
- Standard Interchange Format (SIF)—A format developed by a microcomputer graphic system vendor (Intergraph).
- CAMRAS—A public works oriented format.
- DXF—A format developed by a microcomputer graphics system vendor (AutoCAD).

In summary, the results of the investigation indicated that all formats could basically transfer DOT graphics information.

IGES was more sophisticated with regard to maintaining original mathematical data integrity for geometrical graphics data elements than the other formats. IGES was also more complex to deal with than the other formats.

None of the formats dealt with spiral data elements. All formats (except DXF) adequately handled attribute data. Each of the formats had some mechanism(s) for dealing with data grouping and fonts.

In general, IGES and SIF were rated as most capable and the others were a little less capable of handling DOT graphics data in a desirable fashion.

CURRENT DATA INTERCHANGE PROBLEMS

The data interchange problems noted by the DOTs have been associated with graphics data, because no standard roadway design data transfer process exists as yet. The graphics data transfer processes used by DOTs are proprietary and controlled

Table 2. IG drafting system vendor list.

Vendors Contacted	Vendors Responding With System Doc.	Adequate Information Already Available
Applicon		
Apollo		
AutoCAD		X
Autotrol		
Calma		
Computervision	X	
Diginetics		
Evans and Southerland		
IBM	X (1)	
Intergraph		X
McAuto	X	
Prime	X	
Sperry		
Sun		
Synercom		X

(1) IBM responded with documentation for three IG drafting systems: Graphic Program Generator, CADAM, CATIA.

by the various IG drafting system vendors. The problems arising with using these processes have been varied and numerous. For example, the conversion process may abort and produce no displayable data. Conversion may produce displayed data that in no way resemble the source data; or the data look similar to the source, except they contain some extraneous graphics and may be missing some data; they look exactly like the source data only the data storage requirements are extremely large and grouping of the data is not appropriate to facilitate manipulation of the data during the updating process.

Because two IG drafting systems and two data conversion processes are involved, it has been difficult for DOT personnel to correct these errors in a timely manner consistent with a production environment. However, the underlying causes for these problems can be attributed to such factors as data conversion software limitations, shortcomings, and malfunctions; and source data being created incorrectly to fit the limitations of the transfer file or the receiving system.

Thus, there is a need to:

1. Limit the scope and complexity of the "neutral" file to promote a common understanding of the data elements by all transfer processes.
2. Provide users with more definitive instructions concerning how to use their systems to produce data files that can be readily transferred. Also provide them with any special instructions for properly setting up the data conversion processes to produce desirable results.
3. On the basis of user feedback, continually improve the conversion processes by correcting malfunctions, expanding limitations and shortcomings, and speeding up the overall process where possible.

CHAPTER THREE

INTERPRETATION, APPRAISAL, AND APPLICATION

SUMMARY OF DOT NEEDS AND TRENDS

The investigation of the information gathered from DOTs and other sources clarified the needs and indicated future directions for data transfer for transportation agencies and their consultants.

The overall trends concerning DOT use of hardware and software systems can be summarized as follows:

1. DOT use of IBM mainframe hardware systems would be even greater than reported if all agencies had responded.
2. DOT use of VAX minicomputers will expand with a projected increase in acquisition of large Intergraph IG drafting systems to take advantage of the cost benefits provided by automated drafting.
3. DOT use of microcomputers will most definitely increase because of newer 32-bit microcomputer technology providing greater computational capabilities at much lower costs and the increased availability of low cost software on these machines that can support an ever increasing proportion of the transportation application needs.

Recent changes in DOT staffing policies will have an effect on the volume of interaction between DOTs and consultants. Two factors contributing to an increase in the dependence of DOTs on outside consultants are: (1) Long-time DOT employees are beginning to retire and have become consultants. This has been decreasing personnel and expertise within the departments and increasing the capabilities of consultants in these areas. (2) Staffing levels within DOTs are more likely than before to be kept lower than what is required to handle peak work loads.

DOTs will provide the hub for data exchange of design and graphics data between themselves and consultants. As the DOTs become comfortable with using the new systems available for design and graphics work, more effort will be able to be applied to the integration of external consultants.

In the future, the chances are very good that the roadway design and graphics processing will be almost entirely on the 32-bit microcomputers linked together and linked to complementary minicomputers and mainframes. Since the questionnaire, reasonably low cost 32-bit microcomputer engineering workstations have become a reality in at least one DOT. Various design and graphics application software has become available in this environment and will increase in the future. With the influx of these low cost systems (both hardware and software), the chances of having different systems being used internally within DOTs become greater, as well as between DOTs and their external consultants.

The current needs for DOT data transfer, as was reported from the questionnaire, indicated that, at present, data transfer was not a major concern. It is believed that the primary reason for this current lack of concern was because the respondees were mostly from engineering design groups that were not fully aware of some of the new technology that was becoming available to assist them with their design work.

As our society transitions from a paper-based society to digital, there is no doubt that the need for data standards and transfer processes for all kinds of data will burgeon. The trends in technology previously mentioned will increase data transfer needs dramatically in the future within DOTs and between DOTs and external entities, mainly because of the variety of systems to which DOTs will most likely begin to shift. DOTs transitioning from old systems to new different systems will make good use of any data transfer standards and processes that are available.

The DOTs must be able to control and standardize the data that will be produced by these various systems. The current practice of allowing external contractors to perform contract work on department systems will have to diminish because of security and potential for misuse. The only reasonable approach to the DOTs gaining control of the data is to provide a standard specification to which the data produced by the consultants and received by the DOT must conform. The data standard must be supported by as broad a range of transfer processes as possible.

DESIGN/GRAPHICS DATA INTERCHANGE CONCEPTS

There were a number of concepts that were key to the successful accomplishment of the data interface objectives for both the design and graphics data. These concepts are:

1. The scope of the data and the conditions of transfer had to be limited to that which was necessary to achieve the transportation agency objectives, and was not allowed to become a "universal" data exchange solution. The primary burden of all previous and current efforts has been the need to solve too large and ill-defined problems. A key conclusion of each part of the research project was that with proper limits, the objectives of data interchange can be achieved.
2. The design of the data interchange format had to accommodate as many roadway design and graphics systems as possible for the transportation-related set of data elements. The data format needed to be simple, understandable, generic, accurate, flexible, and expandable to provide a proper standard for the exchange processes.
3. The data interchange file structure had to allow for the interrelationship of the graphics and design data to properly support the data transfer between the currently emerging IG roadway design systems.
4. Information describing the standards, the methods of employing them and the limitations and methods related to exchange of data between specific systems and the interchange file, must be provided for proper use of the procedures. Knowledge of the data compatibilities and incompatibilities is of primary importance for successful data exchange.

INTERRELATIONSHIP OF GRAPHICS AND ROADWAY DESIGN DATA

Currently, only three or four systems are known to exist that contain interrelated graphics and design data. The systems that are currently known are IGrds, Intergraph's Transportation Design Package (TDP), Civil Engineering Applications Library (CEAL), and MOSS. Intergraph's TDP system is probably closest to IGrds in functionality. However, to date, it has only been released as a beta test system, and very little information has been obtainable for this project concerning the TDP system and how graphics/design data are handled within it. No detailed information was available for CEAL or MOSS during the information gathering phase of the project. Therefore, IGrds was the only IG roadway design system for which information was available to use in the design of the interface for exchanging interrelated graphics and design data.

In the IGrds system, related graphics and design data have attribute identifying pointers applied by the programs of the IGrds system. These identifiers allow the user and the programs to understand what the data represent (e.g., an alignment name identifies the meaning of both the design and the graphics data). As interrelated design and graphics data are converted through their respective processes, not only must the mathematical data be translated, but the attribute name must be translated as well. These attribute names must be converted in the design and graphics process so that they will be as compatible and understandable in their respective systems after translation as before. The other IG roadway design systems must operate in a similar fashion to IGrds. The general solution to the problem of interrelationship of design and graphics data in the IGrds system should be equally applicable to these other systems, regardless of the precise mechanisms and structures used by each of these systems.

The general approach that was taken to interrelate the CDIF design and graphics data was to attach pointer information and any other necessary attribute data to the graphics elements that relate to design data. This pointer/attribute information must be attached by the graphics DIPs to the CDIF graphics data elements as they are created during the conversion of the original source data (containing graphics and attribute information). Also, the graphics DIPs must use this same attached information to maintain the appropriate interrelationship when converting this kind of CDIF graphics data back to some other IG roadway design system.

The need for the graphics DIPs to attach and interpret the pointer/attribute data was one of the primary reasons why it was necessary to create at least one nonproprietary graphics DIP that could be modified to demonstrate this capability for this project. Because all known graphics data conversion processes were proprietary, no code modifications could be made to these processes to accomplish the proper attribute attachment or interpretation.

RATIONALE FOR EXCHANGE FORMAT SELECTED

The Initial Graphics Exchange Specification (IGES) was selected as overall the most effective of the various formats investigated for handling the graphics data, and for providing the graphics data structures common to roadway design applications. The IGES format is a nationally recognized standard format that has for years been used as a "neutral" file for the transfer of graphics data between systems. IGES is supported by the National Bureau of Standards (now called National Institute of Standards and Technology) with a great deal of assistance from volunteers from the private sector.

Although data transfer efforts, to date, using IGES (or any other formats) have not been totally successful, the format itself was not considered to have been the culprit other than possibly being a little overly complex. A variety of other factors bore most of the responsibility for the incomplete success of the various data transfer processes. It was felt that the IGES format, in a more simplified form, provided a very good basis for the structure of the CDIF format to be developed under this project to serve the transportation design community. Overall, IGES had the best capabilities in transferring drafting data, defining mathematically exact engineering graphics data, and accommodating attribute data associated with roadway design data. By simplifying the IGES format to support only data required by transportation applications, it was felt that a new neutral CDIF format could emerge that would be easier for transfer processes to properly deal with, while, at the same time, maintaining sufficient accuracy, integrity, and intelligence for transportation specific graphics data.

The IGES file structure was found to be usable as the structural basis for the roadway design data portion of the CDIF file. Even though the design data elements have very little similarity to any of the IGES graphics data elements, the overall structure, with its directory and parameter data records, fits very well with the processing needs for design data.

DEMONSTRATION SYSTEMS SELECTED

It was desirable that at least one data conversion process of each type (design and graphic) be implemented in accordance with the project plan to demonstrate the practicality of the CDIF specification and to serve as examples for the preparation of other data conversion processes.

Four roadway design DIPs were created to provide a complete demonstration of design data transfer, because no design data transfer processes previously existed. The two roadway design systems selected to be used in the implementation of the prototype design DIPs were RDS/IGrds and ICES/COGO/ROADS. These design systems were chosen for several reasons. The investigation of roadway design systems used by DOTs indicated that the two systems were currently the most prevalent and, therefore, would provide the most initial payback. Also, the analysis of the data structures revealed that, although there were substantial differences in the manner in which each of the systems handled design data, there was sufficient common ground to provide a strong possibility for successful data transfer between these two systems for a majority of design data required by transportation agencies.

It was originally thought that it would be necessary to create two graphics DIPs in order to have a complete demonstration of graphics data transfer. The two graphics systems selected to be used in the implementation of the graphics DIPs were Intergraph and AutoCAD. These systems were judged to provide maximum payback because of their broad use among DOTs and their consultants. The Intergraph system, being basically a large, costly, minicomputer-based interactive graphics drafting system, provided an ideal data transfer demonstration when coupled with the AutoCAD system, which is basically a small, low-cost microcomputer-based graphics system with a rapidly growing user base. Investigation of these systems' data structures showed that although the graphics data elements supported and the data formats used were very different for each system, data transfer could be adequately accomplished for the transportation-specific set of graphics data elements most frequently used in DOT graphics applications.

During implementation of the Intergraph DIP, it was discovered that AutoCAD had developed an IGES data conversion process that was provided with their system at no additional cost. Because the CDIF format was purposefully defined to be a subset of the IGES format, it was suggested that this processor be tested with CDIF data to ascertain its worthiness to provide adequate assistance for demonstrating CDIF graphics data transfer. After extensive testing, the AutoCAD IGES processor was found to produce results, with CDIF data, that were adequate enough to warrant by-passing development of this DIP and to use the resources in other areas of the project where more benefit could be gained. It was still necessary to produce one two-way DIP (Intergraph to/from CDIF) to fulfill the needs of

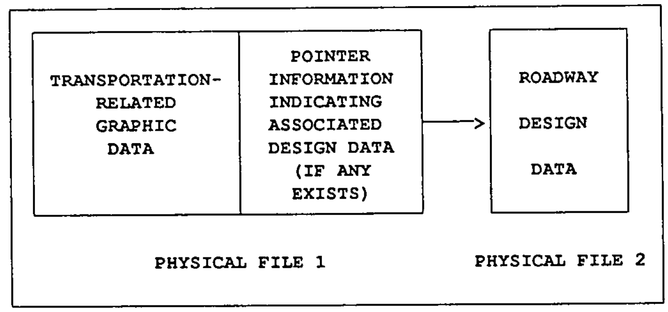

Figure 3. Logical CDIF file.

the project. The benefits and advantages to be gained from the creation of this independent conversion software were as follows: (1) The graphics data conversion software would be in the public domain and, therefore, freely available to the entire transportation community. (2) The software source code can be customized to best fit a specific user's needs. (3) Malfunctions, shortcomings, and enhancements can be addressed by a single support operation. (4) Conversion software can be ported and run on multiple systems (i.e., can run both conversion processes on the same sender's system). (5) The graphics data conversion software can be integrated with the design data conversion process for handling interrelated design and graphics data.

OVERVIEW OF CDIF FORMAT DESIGN

The general CDIF file structure was defined to be one logical file made up of two distinct physical files. One of the physical files represents the design data to be transferred. The physical files are independent, but may be interrelated as shown in Figure 3.

The data structure allows for convenient, independent processing of either graphics data or design data.

For interrelated graphics and design data (i.e., IGrds), the structure allows for attribute data or pointer data to be included in the same physical file as the graphics data. This attribute data describes which design data should be associated with a given graphics element, and will be utilized by the graphics data conversion process to establish the proper interrelationship between the graphics and design data being transferred.

The design is open ended and may be freely expanded in the future. Each new graphics element or design element that is required to be exchanged may have a new format prepared, along with appropriate DIP logic. Any new expansions must be coordinated either with a "standards manager" or with an exchange partner.

DEVELOPMENT OF PROTOTYPE DIPS

The DIP development work effort was broken into the following four general stages: (1) design DIPs for ICES COGO/ROADS, (2) design DIPs for RDS, (3) graphics DIP for Intergraph, and (4) graphics DIP for AutoCAD (testing applicability of existing DIP).

Each of these developments was basically independent of the others, and the design and graphics DIP development efforts were able to be done concurrently with each other. Utility routines were developed and shared between the various processes where possible.

A number of guidelines were followed in the development of the prototype DIPs. Two of the basic concepts adhered to for all of the development was to initially restrict the range and variation of data (design/graphics) and to initially develop base computational software with minimum complexity for the user interface. Later, the processes were to be broadened where possible. Other concepts used in the development of both the design and graphics DIPs involved defining the layout of computer memory transfer arrays for design/graphics data and developing basic utilities to transfer data between these arrays and the CDIF file (in both directions). All software was developed in the VAX environment and written in FORTRAN '77 that can be fairly readily ported to other computer environments.

Initial development began with the implementation of "one-way" DIPs for both design and graphics data. For the design data, the development began with the creation of the processes "from ICES ROADS to CDIF" and "from CDIF to IGrds." These processes together represent the one-way data path "from ICES to RDS/IGrds". After completion of this path for the simple design data, the processes associated with the other design data path were initiated (from RDS/IGrds to ICES). The "from RDS/IGrds to CDIF" process was initially able to be developed for a broader range of data than the process "from CDIF to ICES" because of the availability of more detailed system documentation for RDS/IGrds. The current prototype design DIP development is summarized in the following paragraphs.

Design data types processed by the ICES COGO/ROADS to CDIF DIP include: geometry points, lines, arcs, chains, courses, distances, angles, and directions; horizontal alignments; vertical alignments; Multi-Material/Surface Terrain Model; typical cross sections; template change set (limited); and design alternatives.

Design data types processed by the CDIF to ICES COGO/ROADS DIP include: geometry points, horizontal alignments, vertical alignments, and the Multi-Material/Surface Terrain Model.

Design data types processed by both the RDS/IGrds to CDIF and CDIF to RDS/IGrds DIPS include: geometry points, horizontal alignments, vertical alignments, terrain model, roadway template shapes and locations, roadway sideslope shapes and locations, and station equations.

For the graphics data, the development began with the creation of the "from CDIF to Intergraph SIF" process. The AutoCAD IGES processor was tested and found to provide a reasonably acceptable CDIF file produced from an internally defined AutoCAD graphics file. With the availability of this "from AutoCAD to CDIF" process, the data path "from AutoCAD to Intergraph SIF" was able to be completed with minimum development effort expended. The other data path "from Intergraph SIF to AutoCAD" was completed by developing the "from Intergraph SIF to CDIF" process and testing the AutoCAD IGES process to see if it could process this resultant CDIF data into AutoCAD's graphics format. The testing showed that the AutoCAD IGES process could adequately handle the CDIF data in all but a few special cases. The special cases were eliminated by modifying the "from SIF to CDIF" process and/or by establishing procedures for data input that eliminated some of the problem data.

After the DIPs were completed for the simple data and with the simple user interface, they were broadened, where possible, to include more complex data and a more user-friendly interface.

Currently, the DIP software supports the transfer of the vast majority of graphics elements needed by DOT applications. In the future, the software needs to be expanded to cover line font definition, dimension, uniform rational B-spline curve (for spirals), and text font definition elements.

Lastly, some of the DIP software was upgraded to demonstrate the initial steps necessary in dealing with interrelated design and graphics data. Special design data software was implemented to create an "equivalence table" file that succinctly identifies all CDIF data element names and their associated aliases. The information in the equivalence table is for use by any "from CDIF to System XXX" graphics DIP process for dealing with graphics data that are related to design data. The CDIF names must be correlated with their aliases in the process of converting the interrelated CDIF graphics data elements into "intelligent" displayable graphics elements in any interactive graphics roadway design system environment.

Certain graphics DIP software subroutines were modified to process specific IGrds graphics data that contained attribute information linking it to roadway design data. Horizontal alignment PI graphics elements were initially chosen to be converted as a good demonstration of how interrelated graphics data could be handled. The graphics PI symbol and attribute information were converted from the Intergraph SIF format to the CDIF format where the PI linkage information was stored in a standardized manner. The standard storage format was designed to allow the graphics PI symbol to be identified as a horizontal alignment data element, more specifically a PI, associated with a given alignment, and identified by a given PI number. Additional demonstration software was partially completed to convert other IGrds interrelated graphics data elements like the horizontal alignments (plan view) and tangents between PIs, geometry points/lines/arcs, vertical alignments and VPIs, cross sections, and graphics data associated with template, sideslope, median, and ditches. The CDIF pointer information currently being produced for these additional IGrds elements was very minimal and would need to be expanded when possible in the future.

Although further work was not possible, under the current research program, for processing the CDIF pointer information in the CDIF file back into an interactive graphics roadway design system, it should be noted that processes to accomplish this can be created in the future using the standard data formats currently being produced.

To process CDIF graphics data which include design data pointer information, a "from CDIF to IG design system XXX" processor would need to utilize the "equivalence table" information to match up the graphics data with previously converted design data and generate representative intelligent graphics elements in the "XXX" system that are in some way linked with the proper roadway design information. The methods for linking the graphics and design data will vary, but the CDIF information provided should be sufficient to allow any system to create an appropriate linkage.

Examples of the equivalence table information and the CDIF graphics data with the associated design data pointer information that was produced by these modified routines has been included in the Appendixes.

TESTING OF PROTOTYPE DIP SOFTWARE

The DIP software was able to be adequately "alpha tested" and debugged in the contractor's offices because all of the systems involved were directly available there except ICES COGO/ROADS. The ICES system DIP was, however, able to be initially tested at the contractor's offices in a less direct manner by using extensive test data provided on magnetic tape by the system vendor and the Ohio DOT, who is a user of that system.

The alpha testing was initiated using simple test data specifically prepared for both design and graphics processes. As the malfunctions with the simple data were fixed, more complex data were prepared by the contractor which identified more malfunctions that were corrected. This process continued until the DIP software was able to properly process actual production data (both graphics and design) received from Texas DOT and Ohio DOT. A concise, but thorough, set of test data was developed and included on the magnetic tape along with the DIP software, so that users may test the conversion software at their own site, as well as use the test material as an example to organize their own design/graphics conversion data. After completion of the alpha testing phase, beta testing was initiated at a remote DOT site.

The Ohio DOT, who very generously volunteered to provide production graphics and roadway design data on tape to be used by contractor personnel to test the DIP software at the contractor's offices, also very kindly allowed contractor personnel access to Ohio DOT computer systems to test DIP software at their central facility in Columbus, Ohio. The Ohio system configuration represented a perfect situation for testing both the design DIPs and graphics DIPs.

Ohio was uniquely set up for testing the design DIPs because of having (and using) in-house the ICES COGO/ROADS system on their IBM mainframe system, as well as the IGrds system on their Intergraph VAX system. The ICES system usage was a legitimate example of how a single district office may continue to use, for a period of time, a system that had been the major design system in the past, even after a newer, more technically advanced, system like IGrds was provided. The design DIPs that convert data between these two systems were successfully loaded down and tested on the Ohio DOT Intergraph VAX system using their own, actual production data. Design data were converted primarily in one direction, from ICES to RDS/IGrds, using the prototype DIP software, then tested for validity using the Ohio DOT IGrds system on the VAX.

The transfer of terrain, geometry points, and horizontal and vertical alignment data from IGrds to COGO/ROADS is functional but was not demonstrated because: (1) the incomplete state of the programs to transfer the horizontal and vertical alignment data; (2) the focus on the relative processing methods of the two design systems during a portion of the demonstration day which did not leave adequate time for the VAX computer, to tape, to IBM computer process of COGO/ROADS; and (3) the lack of familiarity of the contractor's staff with the procedures necessary to produce an IBM computer process setup for COGO/ROADS.

For the graphics DIP testing, Ohio also provided a unique setup that not only contributed to a perfect graphics data conversion testing environment, but also clearly demonstrated the need for a better graphics data interface in their production environment. The Ohio DOT uses the IGrds drafting capabilities to produce certain portions of plan/profile sheets on the Intergraph system, and then uses the Intergraph drafting capabilities to further enhance and plot the sheets. Additional information and graphics data are produced on the agency's PC-based AutoCAD system. The additional information is tabular and more easily entered and dealt with on the PC machines. Because of problems in converting data between AutoCAD and the Intergraph systems, the AutoCAD graphics tabular information is usually amalgamated, where necessary, with the Intergraph data by "cutting and pasting" the plotted graphic output from both systems to create the desired final plan/profile sheets. Although this method works and produces the desired results, proper data conversion would be a more desirable solution. The graphics DIPs that convert graphics data between these systems were successfully loaded down and tested on the Ohio DOT Intergraph VAX using their own actual production data. Graphics data were converted in both directions using the prototype DIP software and AutoCAD's IGES data conversion process. The converted graphics data were tested for validity by displaying the resultant graphics files on the Intergraph VAX system and on the PC-based AutoCAD system.

The actual testing of the design and graphics DIP software was performed by contractor personnel with Ohio DOT personnel overseeing the operation. A brief evaluation was made of the results of the initial beta testing performed at Ohio as observed by DOT personnel.

The on-site remote testing at the Ohio DOT demonstrated that the DIP software can be loaded properly on a remote system and operated as well on a remote system as on the contractor's system. Further, ad hoc testing with real DOT production data confirmed the applicability of the interface to meet DOT needs. Some new program errors were also discovered during the tests. User feedback indicated ways to improve the user interface.

Finished production DIP programs will result from careful beta testing and extensive production use as well as user feedback on the program operation. This process normally extends well beyond the end of a design and development project. The existing DIPs provide a foundation upon which future corrections and enhancements can be implemented to make the interface more error-free and user-friendly.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

CDIF Format Specification

The research has led to patterning the structure of the graphics and the roadway design data files that comprise the "logical" CDIF file as closely as practical to the IGES data format (Release 3.0). The graphics CDIF file was structured to conform to the IGES specification so that any existing IGES processes could handle a CDIF graphics data interchange file. The IGES specification was used only as a guideline for the roadway design data because design data were drastically different in character from graphics data and, also, because no neutral files or conversion processes currently existed for the design data.

Both the graphics and the roadway design data interchange files employ the same "classes" or "sections" of data records, except that the contents and the formats of some of these classes may differ somewhat between the graphics and the design data files.

The record classes, or sections, into which the CDIF files are divided are: start, global, directory, parameter, and terminate.

The start and terminate record types are exactly the same for both graphics and the design data, while the global, directory, and parameter records have differences as well as similarities in form, use, and content.

Data Interchange Processes (DIPS)

The processes for interchanging transportation-related graphics and design data can be categorized as three separate processes designed to exchange the three basic kinds of data: graphics, design, and interrelated design/graphics.

Graphics DIPs. The interchange of stand-alone graphics data was accomplished in approximately the same fashion as the currently existing graphics data interchange processes. The only difference was that rather than attempting to convert the entire spectrum of graphics entities that could exist, this process concentrated on converting the well-defined, basic subset of graphics elements related only to transportation applications. The basic approach used for the graphics data interchange processes was to have two processors for each of the graphics systems involved. One of these processors converted graphics data from the vendor-specified format of the given graphics system to the graphics portion of the CDIF file. The other processor converted graphics data from the graphics portion of the CDIF format to the vendor-specified format of the given graphics system. It was only necessary to implement the graphics DIP processes for one system (Intergraph) to adequately demonstrate graphics data transfer.

Roadway Design DIPs. Because there was no prototype that existed for design data transfer, the interchange of stand-alone design data required some limitations on the many possible features that would allow for maximum flexibility in order to ensure that the task of implementing the required interchange processes produced a basic, extendable, and workable product within the resources available to the project. The Roadway Section Definition data is a good example of the need for procedures where certain design systems have definite limitations on the number of data elements allowed for template, slope, and other types of design data. In these cases, the users on the sending system must adhere to certain limitations to ensure effective design data transfer.

The basic approach used for the design data interchange processes was identical to the graphics data interchange processes in that it also employed two processors for each design system involved. However, it was necessary to implement the design DIP processes for two systems (ICES COGO/ROADS and IGrds) to adequately demonstrate design data transfer.

Interrelated Design/Graphics DIPs. There also existed no prototype or example for the transfer of graphics data related to the design data in an IG design system. Therefore, demonstration software was developed using the graphics DIP software as a basis and upgrading it to process IGrds graphics data elements that were linked with design data. The software currently examines the graphics data from an IGrds graphics file to determine if there is some attribute linkage attached, extracts this linkage information, and converts it into the standard form for attribute data in the CDIF format. This standard form uses a keyword-type syntax to define the kind of data (HA, VA, etc.), the associated alignment, the type of data (PI, VPI, etc.), and the identifier of the data element (PI number, etc.). More details on this syntax are included in the Appendixes.

Software was also developed to create an "equivalence table," containing CDIF names and associated aliases for design data elements, which would be used to correlate graphics data elements with the proper design data elements when converting interrelated data from CDIF back to some IG design system. Currently, no software has been developed to convert CDIF interrelated design/graphics data back to IGrds or any other IG design system. However, future development effort can build upon the currently developed software and standards.

Figure 4 depicts, in general, how the interface system works for design systems, graphics systems, and interrelated design/graphics systems.

Implications, Benefits, and Use Of the CDIF Specification and Prototype DIPS

The project research has established that there has been, is, and will be in the future (to an even greater extent) a need for DOTs to transfer design data, graphics data, and interrelated design/graphics data between various systems and between various users. Although the need has been recognized, the consequences of not satisfying this need are not currently serious for most DOTs, as yet. This is a good opportunity to develop a major portion of the software required to solve a given problem before it has become universal, posing serious consequences to users, and forcing software to be developed in a hurried manner which, generally, does not produce very desirable results.

The CDIF specification and prototype DIP software provide a superb foundation for future development which, if adequately supported, can properly satisfy this need before the consequences become so dire. Some form of joint support needs to be mustered as rapidly as possible, because there is currently a veritable explosion in the number of design and graphics systems available on microcomputers and minicomputers, and DOTs are beginning to take advantage of the wide variety of cost-effective systems tailored to solve many of their production problems. As the new systems are phased in and the older systems are phased out, the need for transferring information between these systems will manifest itself within DOTs (e.g., central office and districts), between DOTs, between DOTs and their outside consultants, and sometimes between DOTs and federal agencies (FHWA).

The need to convert archived data from the old system to the new system to perform roadway rehabilitation projects is one example of production work that can be done more efficiently by utilizing the data interface. Outside consultants (and the DOTs themselves) can benefit from the data interface both by being able to work using a familiar low-cost "tool" and, then, by providing the DOT with deliverable data in the form required by the DOT.

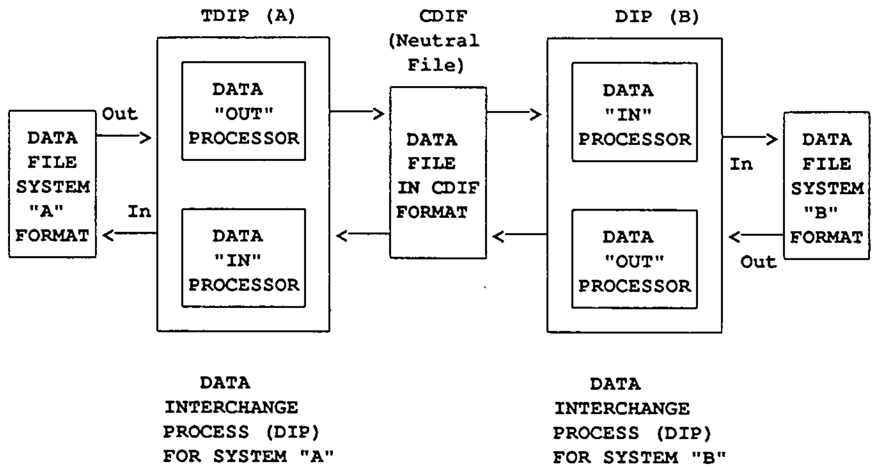

Figure 4. Design/Graphics Interface System

The CDIF specification establishes a much needed initial standard for the transfer of transportation-related design/graphics data that can grow, as necessary, to meet the requirements of a rapidly expanding group of design/graphics systems used by transportation agencies. DOTs have in the past been forced to have outside contractors work on DOT computer systems, or require that they use a system exactly like that used by the DOT, to ensure compatibility of data. Neither of these practices should be tolerated much longer. The CDIF specification provides a data standard that the DOTs can begin to use to define requirements for how data can be presented to the DOTs from all external sources. The data entry guidelines provided with the CDIF specifications can be used by DOTs as a basis for preparing data entry requirements that may not have been specified in the past to external contractors, but have been sorely needed to help simplify some of the current graphics data transfer problems between consultants and DOTs. DOTs can also begin to require in their procurements that system vendors provide design and graphics data in accordance with the CDIF specification as part of their system offerings.

Of necessity, the data interchange processes developed under this project were directed primarily toward demonstrating the feasibility of the CDIF specification and providing a foundation (or examples) for future development, rather than toward creating a set of production data transfer tools for users. However, the current prototype DIPs provide public domain, reasonably usable data transfer processes capable of converting the majority of the essential design data from the ICES COGO/ROADS system to the IGrds system, and the vast majority of the DOT-related graphics data in both directions between the Intergraph (SIF) system and the AutoCAD (IGES) system. These DIPs are in the "beta-test" stage and require a substantial amount of testing, using a wide variety of data, by various external users, and over a fairly long period of time. If the beta-testing can be supported by software modifications as malfunctions are discovered, the DIPs could eventually be considered worthy of a "production" status.

Assuming some kind of support effort is available for enhancing and maintaining the current DIP software, the user can work to transfer design and graphics data between systems that are most commonly used among DOTs (Intergraph, AutoCAD, IGrds, and ICES COGO/ROADS). If problems are encountered, a single support group should be able to be tasked to fix the problem to ensure that production will not suffer any more than absolutely necessary.

The prototype DIPs provide examples that can be followed in the development of new DIP software for other design or graphics systems. They also provide quite a few utilities that can be directly used in the new DIP development for, as an example, creating CDIF records from memory transfer arrays. An effort was made to simplify the user documentation so that the user could better understand the DIP operating instructions and, consequently, to reduce the overall effort required to become adept at transferring various types of data.

SUGGESTIONS FOR FURTHER RESEARCH AND DEVELOPMENT

The major goals and objectives of the project, namely, to establish a standard file format for interchanging design and graphics data, and to demonstrate that the format provided a practical method for this data interchange, were accomplished. The prototype DIP software was developed as fully as the project resources would allow. There were a number of development tasks that were not addressed or that were only partially completed and there are future ongoing tasks that must be addressed, after the conclusion of the project. These tasks fall into various categories, such as CDIF specification and documentation, general DIP development, specific design DIP development, specific graphics DIP development, and specific interrelated graphics/design DIP development.

CDIF Specification and Documentation

For the current interface to become a production tool for use by various DOTs, the current documentation included as appendixes to this report must be reorganized and upgraded to a production level status. Ongoing support would be required to fulfill the following needs:

- Analyze, upgrade, and include into the CDIF specification new data element types or extensions to existing types that may be suggested by users in the future.

- Upgrade all DIP documentation, as necessary, for new elements.
- Distribute all interface documentation to all participating entities.

General DIP Development

All existing DIP software will require substantial revision of, and upgrades to, the current user interfaces to attain a level of user-friendliness that would be acceptable for DOT production purposes. Further effort will also be required to broaden, where applicable, the variations of data that the DIP software will accept for all existing data element types supported. Some of the data restrictions that were necessary for the demonstration DIP software will need to be removed before being acceptable for production use.

Ongoing support should be provided to fulfill the following needs:

- Fix various malfunctions as they are discovered by beta-test users.
- Implement appropriate enhancements to the DIP software as requested by production users to maintain a viable product.

For the interface to serve as an effective production tool, the data transfer pathways supported by the interface must eventually be expanded to encompass more design, IG design, and graphics systems than were included in the current demonstration interface.

Using the CDIF format as the standard, effort will need to be expended in the future to create new DIP software for other design, graphics, and interrelated design/graphics systems that can provide benefit to the transportation community. Various system vendors may provide some assistance in this area, especially if prodded by various states during procurements to provide the capability to interface with the CDIF format as part of their system.

Specific Design DIP Development

The design DIP software developed to-date is comprised of approximately 200 routines and can transfer a majority of the design data in all directions between ICES, CDIF, RDS/IGrds, and memory transfer arrays, except one. The data pathway "from memory transfer arrays to ICES" was only implemented to transfer geometry point, horizontal alignment, vertical alignment, and terrain data. This data pathway must be expanded to include support for all design data element types in order to complete the "from IGrds to ICES COGO/ROADS" transfer process.

The design DIP software for all of the various data pathways needs to be expanded to support the following types of design data: station equation data, superelevation data as-designed cross-section data, and improved method for handling template data.

Specific Graphics DIP Development

The graphics DIP software is comprised of approximately 60 routines and currently transfers a set of graphics data element types that encompasses the vast majority of graphics elements needed by DOT applications. The pathways supported by the software currently include all directions between Intergraph SIF, CDIF, and memory transfer arrays. The AutoCAD IGES processor was able to be used with the CDIF data to complete both the "from AutoCAD to SIF" and the "from SIF to AutoCAD" data transfer pathways.

There are a few graphics element types that were discovered during testing that are currently not supported by the graphics DIP software that probably need to be supported by the software to provide a usable production tool. The graphics DIP software eventually needs to be expanded to include the following types of graphics data: line font definition data, dimension element data, uniform rational B-spline curve element data (spirals), and text font definition data.

Interrelated Design/Graphics DIP Development

To demonstrate how interrelated design/graphics data should be handled, the prototype graphics DIP software was expanded to convert a number of IGrds data elements with related design data from the Intergraph SIF format to the CDIF format. Project resources would allow no more than a very basic portrayal for most of the IGrds data in the CDIF file. The DIP software needs to be upgraded to portray the attribute linkage information in the CDIF file in a more expanded manner for all IGrds data elements in order to provide appropriate linkage information for other interrelated design/graphics DIP processes.

Substantial effort needs to be exerted to develop DIP software to support the data transfer pathway "from CDIF to IGrds". No work has been done, as yet, to support this data pathway. In the future, data transfer processes will need to be developed that can transfer interrelated data between CDIF and various IG design systems, other than IGrds.

FUTURE SUPPORT OF CDIF SPECIFICATION AND PROTOTYPE DIPS

The CDIF specification and prototype DIPs must continue to evolve after this project. Additions, modifications, and other improvements listed in the previous section of this report need to be implemented to bring the CDIF specification and DIPs closer to a production status. Further improvements need to be identified through ongoing beta testing and production use.

In order to provide the future support to fulfill these requirements, a single dedicated clearing house or source for support should be identified so that updates proposed to the Common Data Interchange File (CDIF) and prototype DIPs can be implemented in a controlled manner and the standard interface can be promulgated.

APPENDIXES A THROUGH E

CONTENTS OF APPENDIX ITEMS NOT PUBLISHED

Appendixes A, B, C, D, and E of the final report are not published herewith. They are included under separate binding in the agency-prepared report entitled, "Development of a Design/Graphic Interface System," Final Report, November 1988. A limited number of copies of that report are available on loan or for purchase at a cost of $15.00, from the NCHRP, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

The "Contents" pages appearing in the agency report are reproduced here for the convenience of those interested in the subject area.

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