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THE APPLICABILITY OF TRANSPORTATION INFORMATION MANAGEMENT SYSTEMS FOR STATE DEPARTMENTS OF TRANSPORTATION

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INTRODUCTION

In the last 20 years, state highway departments have undergone a major transition from custodians of the state's roadways to becoming a multifaceted agency responsible for numerous modes of transportation. This changing role has forced DOT's to switch their focus from operational agencies to agencies which concentrate on planning and coordinating information management functions for transportation activities throughout the state. An important prerequisite of these functions is the development of a statewide multimodal transportation information system capability which provides DOT managers with the necessary data for monitoring statewide transportation activities as well as supporting both short and long term decision making processes.

The authors of this report were recently asked by a state DOT to undertake a detailed study to determine the following: (1) ascertain condition variables of the state's transportation system, (2) inventory existing databases from agencies within the state, (3) assess present and future user information needs, and, (4) evaluate information system architectures as they apply to the needs of the users.

The ultimate goal of this study is to determine the feasibility of developing a coordinated Transportation Information Management System (TIMS) which could be equally accessed by the state DOT, city and county municipalities, councils of governments (COG) and non state transportation agencies. This study represents the first significant effort to obtain a statewide description of transportation related information currently being collected and electronically stored, and provide recommendations on how different information system architectures can be managed as a single information system.

METHODOLOGY

Study of Condition

Since the objective of the study is to assess the feasibility of a transportation management information system which describes the condition of transportation systems and infrastructure in the state, the first phase of this study is to determine those factors which constitute condition for the following types and modes of transportation: aviation, bicycle/pedestrian, highways, railroads and transit. As part of the process of defining condition, the authors conducted a detailed literature review of condition information at local, state and federal levels. The purpose of this investigation is to assess previous work performed in the domain of condition and extract those variables which could be used to describe condition in the respective modes of transportation.

This initial stage of research also consists of a detailed interview process involving sixty-seven transportation professionals. These individuals represented local, state and federal government levels as well as profit and nonprofit organizations engaged in or related to the five modes of transportation.

The information obtained through the literature review and the interview process culminated in the development of a listing of condition variables deemed important for each particular mode of transportation. The modal variables were then grouped into functional categories comprising financial, maintenance, operations, physical and safety.

Condition Questionnaire

A questionnaire was developed which reflects previously identified variables and functional categories. The purpose of this research instrument is to survey the opinions of state, county, municipal and special district analysts and decision makers regarding the appropriateness of the condition variables. A standard questionnaire format was developed for all the modes of transportation, however, the variables included are unique for each modal orientation. The purpose of the survey was fully disclosed in a cover letter which accompanied the questionnaire; individual variables are measured utilizing a six-point Likert scale ranging from not important to very important. Demographic information was also solicited for each respondent.

Sampling Frame

The potential sampling frame was developed for each mode of transportation based on recommendations from the interviews conducted in the initial phase and from various transportation related directories. The resulting sampling frame was then reviewed by a State Department of Transportation Steering Committee to determine appropriateness of individuals and for recommendations of additional individuals to expand the sampling frame.

The survey was administered via transmission by facsimile to the individuals listed in the sampling frame. A non-response rate was minimized by follow-up telephone calls requesting the participant's response. Once it was determined that all possible condition questionnaire responses were secured, the data was tabulated and analyzed for each mode of transportation.

Data Availability

In the second part of the study, existing database systems from agencies throughout the state and country were obtained for further evaluation. This process concluded with a total of 139 organizations and agencies being contacted: 75 national, 24 state, and 40 local. Included were profit and nonprofit organizations, and public and private sector organizations. For each of the databases identified, the general nature of the database was identified in order to eliminate databases having little pertinence to the project.

Once the utilization of the databases was identified, data dictionaries were collected and other information concerning general characteristics of the organization, hardware, network capabilities, software, and data retention policy was collected from those organizations responsible for maintaining the databases. Attempts were directed at meeting with the individuals within the organization who are the most knowledgeable that organization's database(s). Typically, this individual was the database administrator, chief information officer, or manager of information systems.

In all, 32 organizations provided 76 transportation-related data dictionaries. From the 76 transportation-related data dictionaries and other database information provided by these organizations, a comprehensive data dictionary was constructed. This compilation resulted in a listing of individual field names and field descriptions across all the databases received. Primarily, this catalog is seen as a survey of available data elements.

Next, the cataloged databases were reviewed for data availability, data comparability, data timeliness, format compatibility, redundancy of data fields, and potential problems with data reliability and data accuracy at both the individual database level and across all databases.

Data Usage

The primary focus of the data usage study is to determine the adequacy of the information provided for determining condition. To do this, a questionnaire was developed to: 1) determine the decision makers that are users of the data gathered to determine condition and, 2) determine their current information needs, with a focus on the data usage relating to condition. The purpose of this is to provide a summary of current data use and the adequacy of this data in describing condition.

A potential sampling frame was developed for each mode of transportation based on recommendations from the interviews conducted in the initial phase and from various transportation related directories. The resulting sampling frame was then reviewed by a State Department of Transportation Steering Committee to determine appropriateness of individuals and for recommendations of additional individuals to expand the sampling frame. The research instrument was administered to approximately 100 users.

The survey was administered via transmission by facsimile or by mail to the individuals listed in the sampling frame. A non-response rate was minimized by follow-up telephone calls requesting the participant's response. Once it was determined that all possible condition questionnaire responses were secured, the data was tabulated and analyzed for each mode of transportation.

A second means for analyzing the coverage of condition is to cross reference the data fields contained in the master data dictionary with the condition variable(s) they measure. By cross referencing the collected data field information to the condition variables identified in Part I of this article, the coverage of these variables provided by the databases was analyzed.

Evaluation of Alternative Information System Architectures

Various information systems architectures for the collection, presentation and dissemination were explored. The ramifications regarding standardized or customized reports, predetermined summarized data, potential users of the system, and integrated data bases were all issues examined in terms of feasibility for a state DOT's information management system.

RESULTS AND ANALYSIS

The following represent the authors' principal findings from the study.

Finding one: There are similarities and differences among variables which describe condition across modes and types of transportation.

Even though modal orientations of descriptive condition variables were noted in the study, conversely certain macro-condition variables also surfaced. Comparison across modes of transportation of those condition variables considered significant by those surveyed denote certain commonalities and trends which cut-across modal boundaries in describing condition. Table I depicts these significant condition variables by transportation mode.

Particular functional areas are more inclined to exhibit commonalities between transportation modes. Below is a summary of the commonalities and differences in the condition variables which were prominent in this study.

In the financial area, a number of trends are apparent. Among these, capital investment and funding are commonly rated as important across all types and modes of transportation. In addition, virtually all types of expenses were rated as important across all modes. These include administration, maintenance, operating, and safety expenses. Lastly, construction/reconstruction costs were generally rated as important across modes.

In stark contrast to financial variables, little commonality across modes was found to exist in the maintenance area. It can be concluded that this is largely due to the condition variables being more modal-specific than global in nature. However, the condition variables rated as important to both the respondents and decision makers are found to largely encompass the maintenance of physical components, for example, the maintenance of aircraft, pavement, bridges, tunnels, and vehicles.

Moderate commonality exists within the **operations** area across all types and modes of transportation. The variable rated most often as important to describe operational condition was efficiency. In addition, service levels seemed to be rated as important. Although not to the same extent as with maintenance, there is still a level of specificity of modal operations that result in different views by respondents and decision makers of the variables which reflect condition.

Within the **physical** area, more modal specific variables were again found to be rated as important. Again, this is largely due to the modal specific nature of the condition variables listed. Two exceptions to this were found, however. The most striking of these exceptions was intermodal transportation links which was rated as important across all modes except aviation. The variable of compliance/conformity to standards was also rated as important across several modes.

Many **safety** variables were rated as important to both respondents and decision makers across all types and modes of transportation. Among these, accident/fatality rates were rated as important in all modes of transportation. In addition, many safety variables with operational components were rated as important across modes. These include in-flight operations, seat belt usage, transportation of hazardous/nuclear materials, and inspections. Variables related to education and trains were also found to be rated as important across virtually all types and modes of transportation.

Finding two: An overwhelming amount of potentially useful transportation data for state DOT's is collected by federal and state organizations across all modes of transportation. This information is stored in public, private and proprietary databases.

Generally, there appears to be a substantial amount of transportation and transportation related data being collected, stored, and utilized by the transportation related organizations contacted. Of the 139 organizations contacted, only 78 responded positively. From these responses, 175 databases were identified. Undoubtedly, these documented databases form only a small portion of the data that exists and went undiscovered by this study.

Of those organizations which provided classification information, 91 of these databases were classified as public, 35 were classified as proprietary, and 23 were classified as private. In our sample, we discovered about twice as many public databases then proprietary and private databases combined. However, the primary factors which affect the availabilities of particular databases include not only the proprietary nature of the data, but also the sensitive or confidential nature of the database, and the ability and willingness of the organization to accommodate the state's request for information sharing.

Another measure of availability is the willingness and ability of the database owner to share the information they control. Of the 175 reported databases, the project team received valid data dictionaries from 32 organizations, for a total of 76 databases: 14 aviation, 2 bicycle/pedestrian, 22 highway, 12 railroads, 10 transit, and 16 non-modal in nature. Included in this number were data dictionaries of proprietary and private databases. Generally, the larger and more "public" the organization, the more willing and able the organization was to provide available information. The willingness of organizations to provide data dictionaries, however, may not be a true measure of availability, since the willingness and ability to share actual data may be impacted by the proprietary or private nature of certain organizations and their databases.

Finding three: Collectively the data bases provide broad coverage of the most important condition variables.

At the macro level of condition variables, an examination of the results of the cross referencing effort indicates relatively even coverage of the major categories of condition variables. The results of the order of coverage by the number of individual data fields were: physical, 613; operational 555; maintenance, 426; financial, 423; and safety, 401.

However, at the first level of aggregation, where condition variables "inherit" data elements from lower level variables, certain observations are noteworthy. This is especially true with regard to lack of coverage. There was a decided lack of coverage of financial performance, of which only 11 data fields were devoted, and the financial variables regarding economic development/impact exhibited no coverage whatsoever. The maintenance variables dealing with transportation facilities (1) and the number of maintenance employees (0) also exhibited a lack of coverage.

In the area of operations, the condition variable of performance enjoyed a very extensive level of coverage with 479 data fields. The least covered condition variables in the operations area were weather (9) and services provided or as it pertains to customers and would be customers (3). The physical variables not covered included intermodal transportation links with a coverage by three data fields, and facilities with none.

In general, the safety variables received even coverage with the exception of accident and fatality rates, which exhibited substantial coverage with 526 individual data fields.

Finding four: Database content reflects the special and selective information needs of its primary users within the state. Data sharing across state organizations and agencies is not occurring.

In most cases, the data collected and stored by an organization is uniquely specific to its mission, objectives, and modal orientation. Given the existing modal specific orientation of most transportation entities in the state, this design is understandable. This is evidenced by the cross referencing of data items to condition variables. The level of coverage of condition variables varies considerably for each database. Some of the condition variables are covered extensively by existing databases, while others appear not to be covered at all. In cases where the condition variables within the data dictionary are very specific, or of interest to multiple organizations, the coverage is quite complete. Condition variables which are more general in nature tend to be less completely covered.

Rather than the rule being that several users reported using the same database, the rule was that each user reported using his or her own specific database. Generally speaking each respondent had at least one or more unique databases that were not used by any other user in the survey. Databases were often locally generated and/or developed for local specific use. In addition, many appeared to be developed in order to provide information for a specific task. Whether users were aware of where the original data came from for the databases was unclear.

Finding five: The methods of collecting and storing transportation data reflect a parochial approach to information management. The current database environment can be characterized as significantly heterogenous. Network capabilities for sharing data exist but are relatively undeveloped.

The size and type of computing hardware used by organizations were generally found to be a reflection of the size of the organization, the amount of data stored and processed, and the length of time the particular information system has been in existence. In other words, mainframe and mini computers were more evident in large organizations that own and maintain very large databases, and have experience doing so for some time. It is interesting to note, however, the popularity of standalone PC-based systems and PC-based systems with the capability to connect to other personal computers and larger computers. This agrees with the trend across all computing situations, enabled by the ever increasing processing power and affordability of personal computers.

Of the information regarding hardware platforms which was received, 80 were PC-based, 3 were Work Station based, 25 were Minicomputer, and 44 were Mainframe platforms. The most popular Mini was the DEC VAX, and the most popular mainframe was IBM.

The software platforms used to store information were found to vary widely also. When information was supplied, respondents indicated that there are 100 different commercial packages in use ranging from word processors to full relational databases. There are also 49 cases of custom built systems, 32 of which were built in-house and 17 were outsourced.

A related issue to hardware platforms is the ability to connect the individual platforms across geographically diverse sites. Such connections fall under the domain of local, metro, and wide area networks known as LANS, MANS, and WANS, respectively. While many organizations that use electronic data storage exhibit LAN capabilities (33) and dial-up capabilities (58), only 24 are connected to MANs or WANs, 45 indicated no network capabilities at all, and 33 provided no information regarding network capability. Thus, when considering the physical mechanism for sharing data, the relatively undeveloped network capabilities present both difficulties and opportunities.

Finding six: There are five information system architectures suitable for developing TIMS. The five architectures are:

1. A clearinghouse for locating transportation databases.
2. A centrally controlled document retrieval system for access to transportation reports.
3. A centrally controlled multimodal database.
4. A centrally controlled data warehouse.
5. DOT-sponsored transportation systems.

The five alternatives are outlined below. The first two are low cost, short-term solutions to some of the state's intermodal data problems. The last three are more expensive, long-term solutions to providing multimodal data. These alternative TIMS architectures are not necessarily mutually exclusive nor are they equivalent solutions, each approach has its limitations. The state might want to pursue all five on varying scales or create hybrid solutions.

1: Clearinghouse for Locating Transportation Databases

The integral component of a clearinghouse is a catalog for documenting transportation databases. Cataloging all available databases is a necessary first step in any data integration effort. Further, if the catalog was put on the transportation network or physically distributed in electronic media form, a state DOT would have a product for providing on-line information about transportation databases to all users in the state. This would demonstrate that DOT's leadership in establishing a cooperative effort to bring organization to statewide data collection in the area of transportation. Furthermore, the database catalog represents the first component of a blueprint for overall information systems development in the state, specifically a move toward a common data architecture.

2: A Centrally Controlled Document Retrieval System

A great deal of transportation information for typical state DOT functions is contained in reports. If these reports were cross-referenced based on key words and topics, and stored in an electronic document retrieval system, state DOT's and other transportation agencies could have ready access to important transportation data. The data would already be formatted for decision making and stored within a single computer system, as a result, nontechnical data users would be able to access the data directly.

However, the data would be limited to aggregated data which are routinely reported and it would not be in a form suitable for further computer analysis. The system would facilitate the sharing of data between entities, but it would not promote the development of an integrated data collection effort.

3: A Centrally Controlled Data Warehouse

A centralized data warehouse achieves a high level of data integration and comparability through careful data engineering. The unplanned inclusion of data from various sources usually involves extensive redesign and modification of many operational databases. Centralized data management works well for supporting an organization's routine operations and for other information a state DOT is responsible for collecting. This approach is worth investigating for developing a multimodal database if a state DOT decides to reorganize itself around a comprehensive multimodal orientation, such as that described in the ISTEA proposal.

4: A Centrally Controlled Executive Information System

An Executive Information System (EIS) differs from a central data warehouse in that an EIS is a central repository for crucial data that is uploaded periodically from operational systems databases within a state DOT and databases that are maintained by other agencies external to DOT. EIS's are most appropriately used to support strategic decision making.

The primary advantage of an EIS is that it does not require a state DOT to completely redesign and integrate hundreds of modal databases that utilize different information technologies. Since common keys and data standards are not uniformly applied across all data sources, approximations in measuring condition are necessary. In cases where the data is not acceptable, feeder databases need to be redesigned if the data is to be included in the data warehouse.

The EIS concept may be particularly appealing to a DOT since its information needs will always include private, public, and special purpose databases that are not designed specifically for the DOT. An EIS provides the flexibility needed to integrate data from disparate sources. The form and content of the warehouse evolve with decision-makers' needs and data availability.

5: DOT-Sponsored Transportation Systems

A state DOT relies upon numerous transportation agencies for the collection of data. The majority of these agencies have some level of computer support; however, a substantial number of the agencies surveyed by the research team report that no electronic storage of information is utilized. Agencies that do use computer systems vary significantly by the size and type of computer systems used. Smaller agencies which operate PC-based systems and those that do not yet use computer-based transportation systems might benefit from a state DOT-sponsored transportation systems that would assist both the state DOT and the transportation agency in data collection and reporting.

ANALYSIS AND RECOMMENDATIONS

Clearly, a state DOT's diverse and multitudinous information needs and its reliance upon external agencies for information complicate data management. Recommendations follow that are designed to assist a state DOT in further determining the TIMS information requirements that can guide the development of an information system that facilitates information sharing and provides a multimodal/intermodal data orientation. The two major architectures for developing TIMS are a corporate data warehouse (CDW) and an executive information system (EIS); figure 1 lists the fundamental characteristics of each. The CDW and EIS are not viewed as alternative architectures but as complements to each other. The CDW is used to store data which the state DOT is responsible for collecting. The EIS draws upon the CDW and other non-DOT data sources to provide managers with information for planning and control purposes; this relationship is shown by figure 2.

Recommendation one: Develop a Centrally Controlled Corporate Data Warehouse Based on ISTEA Management Areas.

ISTEA Management Systems propose to increase efficiency and effectiveness and achieve strategic goals of the state by grouping together logically related transportation activities and decisions. Information systems are to be constructed to support these activities. The overall effect is integration across transportation modes. In general, these systems are primarily intended to support tactical and operational activities that, when completed satisfactorily, meet the strategic goals of the state.

Systems developed along the lines of ISTEA will be based upon a CDW architecture which provides data integration and comparability through careful data engineering and commonly agreed upon data definitions and standards. This approach requires all important transportation data to be stored on interconnected machines in compatible formats. Relevant information could then be easily transferred from machine to machine or to one central, integrated database. This approach is feasible for only data a DOT wishes to collect and store itself; such a classical, centrally controlled, database management approach is impractical for storing data from various non-DOT transportation agencies as outlined in the previous section of this article. Even when considering only the structural and format differences indicated by the diversity of hardware platforms and software packages, it becomes obvious that any attempts at overall integration would require very significant efforts and cooperation between the owners of the data. Furthermore, the unplanned inclusion of data from various sources usually involves extensive redesign and modification of many CDW tables in order to maintain a high level of data integration.

For these reasons, a CDW is generally viewed as a costly, long-term endeavor. Many corporations move existing applications into the CDW as they become obsolete and a complete system overhaul is necessary for continued operation.

Recommendation two: Develop a Centrally Controlled Executive Information System (EIS) for Management Reporting and Intermodal/Multimodal Information Needs.

An EIS differs from a CDW in that an EIS is a central repository for crucial information that is extracted periodically from operational systems databases within a state DOT and databases that are maintained by other agencies external to the DOT. The CDW is a repository for subject-oriented information which is accessible through a graphical-user interface (GUI). EIS's are most appropriately used to support strategic decision making and management reporting.

As depicted in figure 2, as the CDW is developed, it will provide valuable data for the EIS to process and to store as information. However, the EIS will augment this information flow with data extracted from various other transportation agencies and data internal to DOT but is not yet included in the CDW physically. In addition to the traditional information formats, the EIS may contain other types of information that do not fit into a CDW such as special studies and newspaper articles describing the political and public opinions regarding transportation issues. As multimedia technology is perfected, digital sound and video formats may be included.

The primary advantage of an EIS is that it does not require a state DOT to completely redesign and integrate hundreds of modal databases that utilize different information technologies. In many cases, approximations to measuring condition are necessary since data is not based upon common data standards and definitions. Despite these limitations, a high level of integration is possible through the cross referencing effort (as described in the methodology dealing with data usage) which provides a framework for establishing a link between condition variables and existing data fields and by extension the tables/divisions and databases on which they reside. This mechanism, if applied on a larger, more inclusive scale, could provide a method of grouping items of interest based on the importance of the condition variables analyzed in this report. A possible implementation of this framework is the inclusion of keywords based on condition variables in a master data catalog; this becomes the vehicle for locating data elements, databases, and the associated controlling organizations.

The EIS concept may be particularly appealing to a State DOT since its information needs will always include private, public, and special purpose databases that are not designed specifically for a State DOT. An EIS provides the flexibility needed to integrate data from disparate sources. The form and content of the warehouse evolve with decision-makers' needs and data availability giving the system long term viability. Since the EIS is an opportunistic approach to information management, it is attainable in the short term. Corporations have successfully developed such systems within one year using off-the-shelf software/hardware components.

The most significant shortcoming of EIS is controlling the cost of loading information into the EIS. EIS technologies have been developed to facilitate the automatic extraction of data from various disparate data sources; however, these technologies were designed to work within a single computer environment. How well these technologies can be applied to multiple computer environments remain to be seen.

CONCLUSIONS

This study indicates that it is possible to build a Transportation Information Management System which incorporates variables which describe the condition of the State's transportation infrastructure and system. However, the study has also identified those areas and problems which require substantial effort and research prior to the development of a meaningful transportation information management system.

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TABLE I
IMPORTANT CONDITION VARIABLES
AS INDICATED BY MEAN RATINGS OF 4.5 OR ABOVE

FINANCIAL	AVIATION	BICYCLE/ PEDESTRIAN	HIGHWAYS	RAILROAD	TRANSIT
Capital Investment	X		X		X
Construction/ Reconstruction Costs	X	X	X		
Economic Development Impact Funding	X		X		
Profit/Loss Performance	X				
Funding	X	X	X		X
Maintenance Expenses		X	X		X
Operating Expenses		X	X		X
Capacity Improvements			X		
Carrier Considerations			X		
Safety Expenses			X		
Administration Expenses					X

MAINTENANCE	AVIATION	BICYCLE/ PEDESTRIAN	HIGHWAYS	RAILROAD	TRANSIT
Aircraft	X				
Communication Navigation Systems	X				
Landways	X				
Lack of Obstructions/Surface Interruptions		X			
Pavement Quality		X			
Bridges			X	X	
Pothole Filling		X	X		
Signage			X		
Snow/Ice Sanding			X		
Striping			X		
Surface/Pavement Quality			X		
Tunnels			X		
Railways				X	
Trains				X	
Vehicles					X

OPERATIONS	AVIATION	BICYCLE/ PEDESTRIAN	HIGHWAYS	RAILROAD	TRANSIT
Efficiency	X		X		X
Weather	X				
Access		X			
Capacity			X		X
Congestion			X		
Demand			X		
Design/Layout			X		
Legislation & Regulation			X		
Abandonments				X	
Service Levels				X	
Passengers					X
Services					X

PHYSICAL	AVIATION	BICYCLE/ PEDESTRIAN	HIGHWAYS	RAILROAD	TRANSIT
Landing Facilities	X				
Runways	X				
Bridge/Tunnel Construction		X			
Continuous Route		X			
Design/Layout		X			
Intermodal Transportation Links		X	X	X	X
Location of Bikeway		X			
Road/Shoulder Width		X			
Signage/Striping		X			
Surface Pavement Quality		X			
Bridges			X		
Conformity to Standards			X		
Intersections			X		
Pavement Quality			X		
Traffic Controls			X		
Compliance with Federal Standards				X	
Interrail Links				X	
Equipment					X
Facilities					X
Vehicles					X

SAFETY	AVIATION	BICYCLE/ PEDESTRIAN	HIGHWAYS	RAILROAD	TRANSIT
Accident/Fatality Rates	X	X			
Aircraft	X				
Air Traffic Control Systems	X				
Communication & Navigation Systems	X				
In-Flight Operations	X				
Pilot Training	X				
Security	X				
Snow/Ice Removal	X				
Education		X	X		X
Personal Security		X			X
Property Security		X			
Traffic Volumes		X	X		
Crash/Fatality Rates			X	X	X
Regulations			X		
Road Conditions			X		
Seat Belt Usage			X		
Sight Distance			X		
Compliance with Federal Standards				X	
Hazardous/Nuclear Materials Transportation				X	
Alcohol/Drug Testing					X
Equipment					X
Inspections					X

X = CONDITION RATING OF 4.5 OR OVER.

CORPORATE DATA WAREHOUSE

- Data Standards
- Data Integration - Common Key
- Data Integrity
- Long Term Phase In Approach
- DOT Collected Data

EXECUTIVE INFORMATION SYSTEM

- Subject Oriented Repository of Information
- Historical
- Easy Access Through Push-Button Interface
- Evolves Over Time with Changing Information Needs
- Short Term Feasibility - Long Term Viability

Figure 1 CDW and EIS Characteristics

Relationships

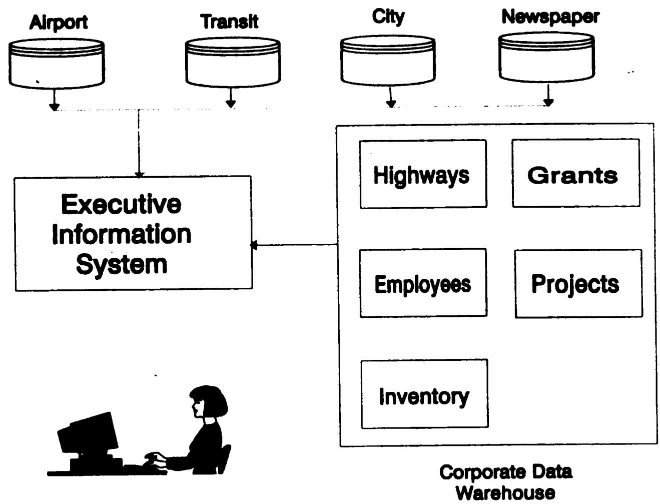

Figure 2 CDW EIS Relationships