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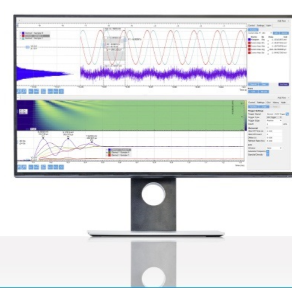

A Comprehensive System for Management Roadway Infrastructure

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Abstract. Utility infrastructure assets in the United States continue to grow as millions of utility features were installed within the properties of state and local agencies. With this growth, the management of the utility data records is becoming a complex problem in terms of large amounts of data. On one hand, management of data for utility infrastructures is extremely valuable to state and local agencies because the timely access to utility-related information is a significant requirement for the delivery of construction and renovation projects on time and within budget. On the other hand, many challenges arise, such as difficulties in effective data storage of complex and messy datasets, data analysis, and data visualization. Utility owners face challenges in collecting utility data in standardized formats, data storage, and providing easy access to all stakeholders. Using a case study in Nevada, this paper demonstrates how tools and a strategic workflow process can be harnessed to develop an end-to-end management solution for large and complex data of a utility infrastructure. This end-to-end utility data management solution builds upon existing systems which are not adequate for large utility data management because they are non-scalable, do not allow for access by multiple users, involve manual data uploads, do not control consistency of data attributes, and lack visualization tools for non-GIS experts. In addition, they do not provide an end-to-end data management pipeline from data acquisition, through data integration, quality control, storage and finally to data access. The developed system in this case study was used for an end-to-end management test of large data during the testing phase and proved to perform seamlessly. Our approach could be adopted by other utility jurisdictions to manage their utility data. Such a data management system allows for automated and proper management of utility data thereby helping state and local agencies reduce utility conflicts and offset construction costs due to utility damages. This data could be combined with other rich data sources, such as financial data, and mined for valuable, hidden insights.

INTRODUCTION

Data-driven decision-making is becoming feasible on a broad scale, and there is growing enthusiasm for a wide range of applications of big data. The definition of 'big data' is relative, and depends greatly on the context in which it is used. Usually, big data includes data sets with sizes beyond the ability of commonly used software tools to capture, manage, and process information within a tolerable length of time (1). Some have defined big data as a set of techniques and technologies that require new forms of integration to uncover large hidden values from large datasets that are diverse, complex, and massive (2).

Geographic Information System (GIS) utility datasets are characterized by volume, complexity, and variety. State and local agencies manage huge utility infrastructure assets that consist of millions of utility features installed within their right-of-ways (ROW) (3).These datasets typically are stored as shape files, geo databases, Computer Aided Design (CAD) documents, image files, Extensible Markup Language (xml) files, and Portable Document Files (PDF),

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to mention but a few types. Various sources provide these datasets to the agencies, such sources as local utility jurisdictions, Sub Surface Utility Engineering (SUE) companies, and utility owners operating in each state. These sources as well as the large variety of types of storage for these huge datasets contribute to the complexity and confusion. Yet, management of big data for utility infrastructures is extremely valuable because timely access to utility-related information is a significant requirement for the delivery of services to consumers, the safety of construction crews and consumers, and the construction of new projects on time and within budget.

Issues related to poor management of sub-surface utilities create significant delays in construction projects (4).This is because utilities often are not considered during the design of some public infrastructure, such as highways(5). Moreover, most state and local agencies lack accurate information on the location of sub-surface utilities within their right-of-ways. Some of the major factors leading to construction delays include inadequate estimation of time and costs for conducting utility relocation activities coupled with poor coordination and minimal cooperation between agencies and Sub-surface Utility Engineering (SUE) companies (4, 6, 7, 8, 9). Ultimately, this leads to the frequent relocation of underground utilities, which is very costly and time consuming.

Considering the significant negative effects of poor utility management, many agencies are interested in including utility engineering processes in their design standards for public infrastructures. This includes the development of comprehensive GIS databases to store utility-related information that can be accessed easily by utility companies and transportation agencies (10, 11, 12, 13, 14, 15, 16). Using a case study in Nevada, this paper demonstrates how tools and a strategic workflow process can be harnessed to develop an end-to-end management solution for large and complex data of a utility infrastructure. This case study developed an end-to-end utility data management solution that builds upon existing systems in previous articles (10, 11, 12, 13, 14, 15, and 16). These previous systems are not adequate for large utility data management because they are non-scalable, do not allow for access by multiple users, involve manual data uploads, do not control consistency of data attributes, and lack visualization tools for non-GIS experts. In addition, they do not provide an end-to-end data management pipeline from data acquisition, through data integration, quality control, storage and finally to data access. The developed system in this case study was used for an end-to-end management test of large data during the testing phase and proved to perform seamlessly.

CASE STUDY

To demonstrate an effective management solution for a large amount of utility infrastructure data, this paper describes a workflow process and a comprehensive GIS database system and management tools developed for utilities within the ROW of roadways maintained by the Nevada Department of Transportation (NDOT). Many construction and reconstruction projects require the location of utilities within the right-of-way of roadways of any State Department of Transportation (DOT). If a DOT lacks a database with all the required information about the location of utilities, each project typically would require significant resources in order to locate the utilities. A GIS database system that includes the location of the utilities will provide all the required information for construction and reconstruction projects.

In this case study, the database system was designed to provide utility data by means of a web portal and ArcGIS, developed by the Environmental System Research Institute (ESRI).Users could access the enterprise database directly by using administrator-provided logins and user accounts. In order to ensure that the database provided the expected service, it was implemented, reviewed, and tested.

The proposed design provides practitioners with a comprehensive methodology to develop robust databases that can be accessed easily. Most importantly, this study highlights all the important components required to accomplish a design process for a comprehensive database comprehensive database. These important components include planning; holding stakeholder meetings; creating an inventory of available data, using the right combination of software tools; incorporating national standards for SUE; developing a pilot project(s), data collection, database design, data conversion, and implementation of the database system; and development of visualization tools.

WORKFLOW OF THE DEVELOPMENT PROCESS

Studies reveal a common process adopted by researchers in creating a GIS utility layer (10, 14, 25, 26, 27, 28, 32, and 33). The process involves a series of stages in chronological order, including planning, development of a pilot project, data collection, database design, and implementation of a utility layer. While this general process is a guide, it lacks the intricate and important details that facilitate the development of a GIS database for utilities.

This study provides specific details and requirements that are not mentioned by other studies, and yet are vital. Figure 1 illustrates the proposed workflow process, using a high-level diagram.

Planning

The planning stage, perhaps, is the most important stage in the database design project because it determines the success of each subsequent step. Generally, the planning stage in this study involved identifying stakeholders, conducting meetings with stakeholders, describing information products by means of a needs assessment, creating an inventory of available data, creating a system design, determining system requirements, designing a database schema, conducting a pilot project, and preparing an implementation plan.

Stakeholder meetings were conducted with the aim of learning about network systems, business procedures, data properties, information technology (IT) requirements, and other important issues related to the management of right-of-way and utility data. These meetings covered a wide range of topics, such as the SUE permit process at NDOT, right-of-way acquisition, GIS practices, and data properties expected from the SUE companies. Considering that several groups are likely to use the GIS utility database – including information regarding the GIS locations, design, ROW utilities, and surveys – it was important to determine their individual needs.

During the planning stage, the research team reviewed the five available national standards for subsurface utility engineering in terms of locations, including standards for the U.S. (17), Malaysia (18), Canada (19), Australia (20), and Great Britain (21). The general objective of these standards was to help engineers collect, represent, and map sub-surface utility data, including defining the quality of a location and attribute information. The Canadian standard was used to select attribute information for different utility types, including water, wastewater, gas, petroleum, electric, and telecommunications (Figure 2). The reason for this choice was that NDOT currently uses this standard for its utility policy.

Another fundamental component of the planning process involved conducting pilot projects for testing the tools that were developed as part of this project. This helped to evaluate the design of the tools and identify compliance issues, which subsequently were refined to ensure that the right strategy was adopted before committing to wide-scale implementation. All these activities in the planning stage finally culminated into an implementation plan that was sanctioned by all the stakeholders.

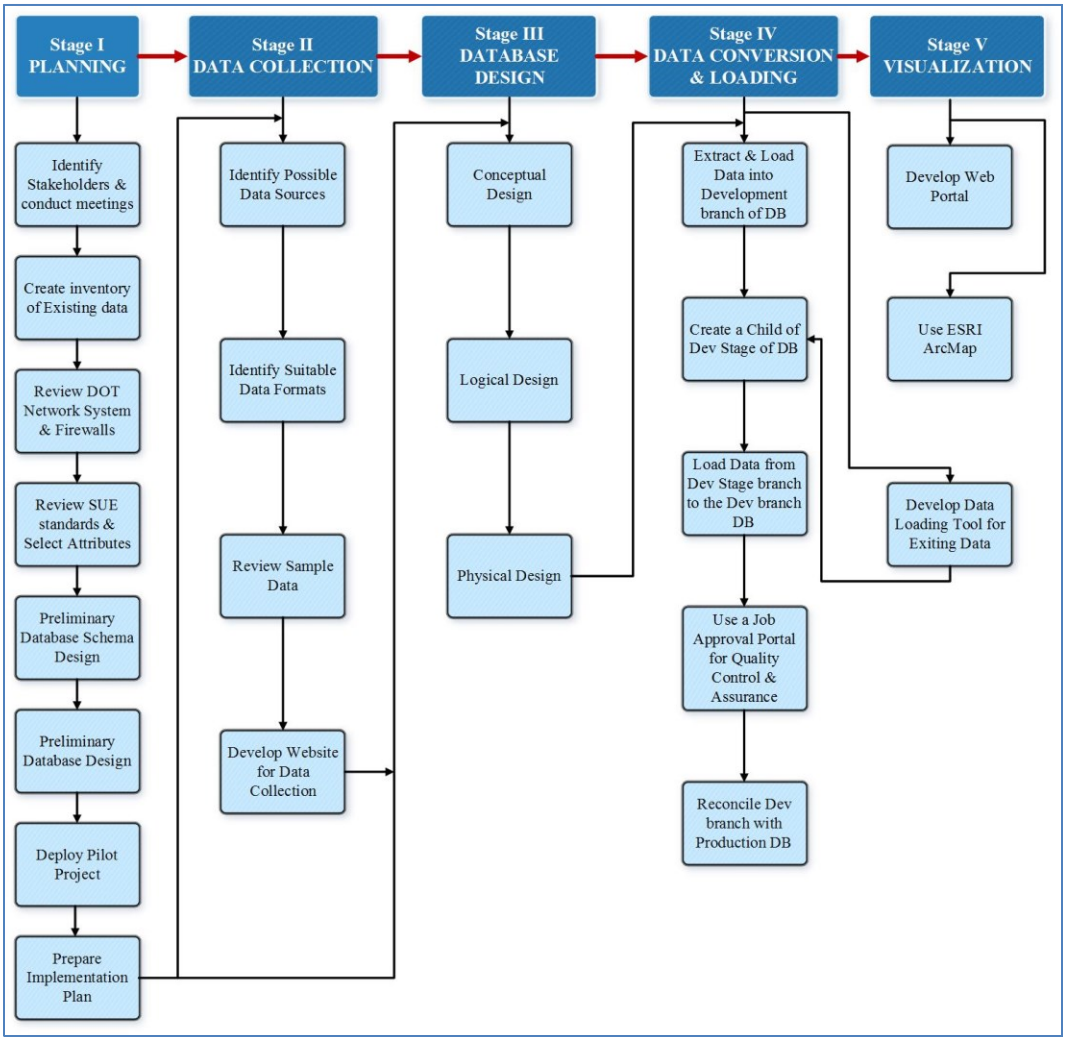

FIGURE 1. Workflow diagram for developing a GIS database for utilities.

Data Collection

The planning stage helped identify potential sources and formats of data. The GIS system developed in this study was designed to accept utility data in many electronic formats, including GIS shape files, databases, and XML files. During the study, it became evident that inventory data formats in the form of pdf, tiffs, and jpegs were not easily convertible to a GIS format. In addition, this data did not have proper scales, was out of date, and had no coordinate location information to geo code the data spatially to the GIS. Therefore, an Optical Character Recognition (OCR) tool was developed to convert scanned documents into computer-readable text.

The analysis of existing data revealed significant issues, one being the lack of a proper coordinate reference system. Hence, NDOT is working on placing stringent requirements on the new data. Data providers are going to be compelled to provide data that has geographic references, location information, and an input form that collects general information about a specific project or metadata. This ensures that new data has the correct geometry information and could be uploaded into ArcMap correctly.

Database Design

Database design is a vital – and perhaps the most challenging – stage in the development of an effective utility management system. Effective GIS applications require a database that provides appropriate information that is accessible and useful by all users. The design needs to take into consideration that various users have different skills and different levels of familiarity with databases and GIS tools. It is important for users to determine the type of geodatabase that is suitable for their needs as well. This is because geodatabases vary in size; cost; ease of usability; number of users; and scale from small, single-user databases up to larger workgroup and enterprise geodatabases accessed by many users.

There are three types of geodatabases, namely, file, personal, and ArcSDE databases (28). In this study, an ArcSDE geodatabase was selected because it was the format recommended by ESRI for ArcGIS datasets, and was managed by a relational database, Microsoft's SQL Server. During this study, industry-standard protocols (23, 28) were followed in a three-step process for the design of the database, including the conceptual, logical, and physical design as well as a data dictionary. While available ready-to-use data models are available from ESRI (29,32), custom data models were developed in this study to meet NDOT requirements. The database consisted of12tables for point and line features for each of the six utility types, a projects polygon table, and a table for the type of job (SUE or survey jobs). Details of the database design and implementation are documented in another paper currently in press (34).

FIGURE 2. Attributes for the six types of utilities which is include a) water, b) waste water, c) electric, d) telecom, e) petroleum, f) gas.

Data Conversion and Loading

The most challenging and time-consuming part of implementing a utility database system is the data conversion process. This study followed a series of steps to convert the data from its original format into database tables in MS SQL Server 2008 R2.Data in geodatabase xmland shape file formats, submitted through the SUE & Survey Website (Figure 3), were loaded into the database, using Python scripts to automate the entire process. Details on the specific functionality of the python loading scripts are outlined in another paper currently in press (34).

FIGURE 3. The SUE & Survey Website.

Visualization Tool

Various users of the database include GIS specialists, CAD designers, surveyors, and non-technical personnel. Based on their technical abilities, each group requires a different mechanism to access the utility data. As a result, a web portal (Figure 4) was developed for read-only purposes. In addition, the ESRI ArcMap could be used to read and write data into the database. Using the web portal, users could visualize utility data by activating its layer and simply clicking on a point, line, or polygon feature in order to display an attribute table.

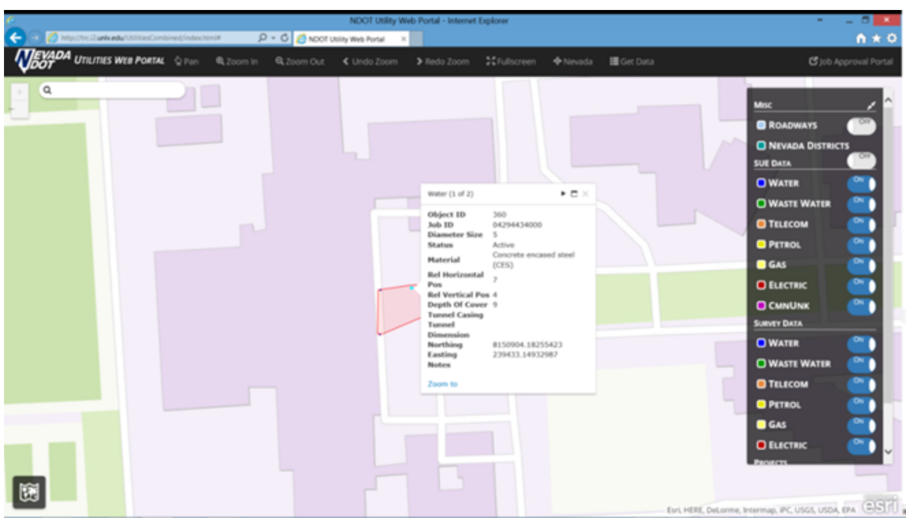

FIGURE 4. Attribute table displaying utility data in a web portal.

Quality Control Tool

Another web portal was developed to provide capabilities to perform Quality Assurance/ Quality Control (QA/QC) by allowing an administrator to approve or reject submitted data from SUE or surveying projects (Figure 5). This ensured that good quality data resided in the database, which allows for good decision making by policy makers at high levels of governance in state and local agencies.

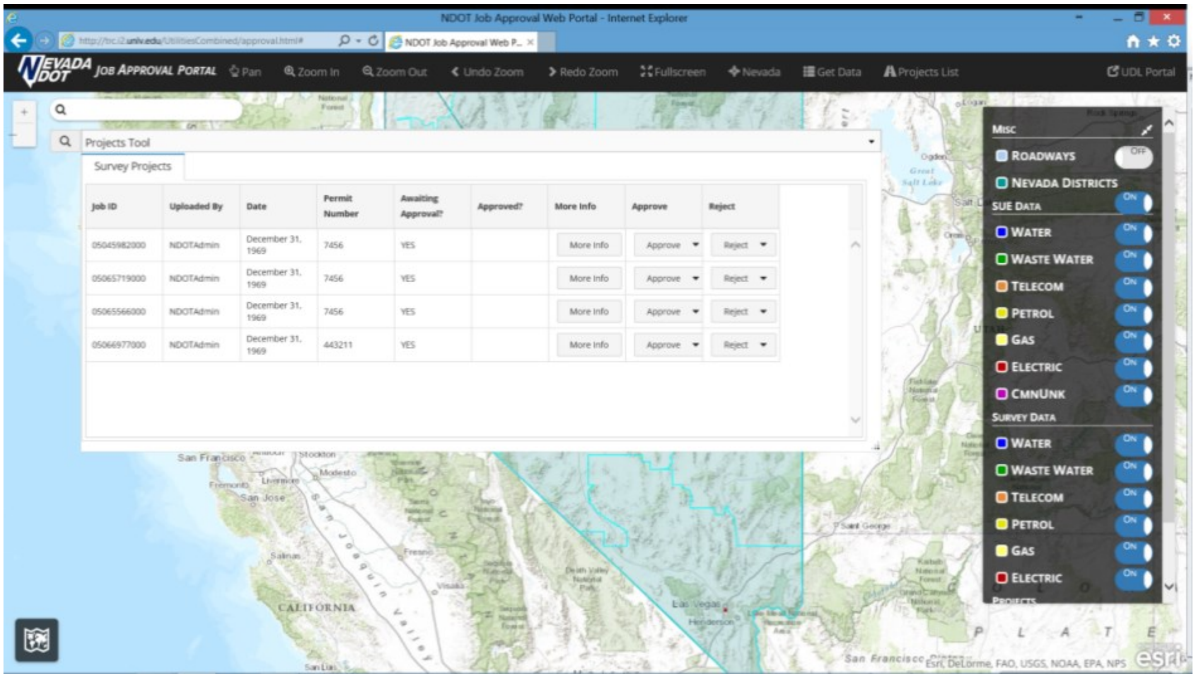

FIGURE 5. Job Approval Portal showing projects pending approval.

Data Loading Tool

Huge volumes of existing utility data reside in disparate databases and folders at state and local agencies and with utility owners. This data needs to be combined into a single database for effective management and decision-making. For this case study, a Data Loading tool was developed for this purpose (Figure 6) to load existing data with different schemas into the database schema of NDOT. The tool provides a Graphical User Interface (GUI) for loading existing data from shape files, geodatabases, MS SQL databases, and Oracle databases. The loading process involves identifying each field of the existing data that matches fields of the target database, and then dragging corresponding fields that need to be matched. Details of the design and implementation of this tool are documented in another paper currently in press (34).

FIGURE 6. Source field names dragged to match target field names.

WORKFLOW OF THE DEVELOPED SYSTEM

The workflow of the developed system, shown in Figure 7 above, illustrates the sequence of processes, tasks, and resources in the utility data management process. This process broadly involves four stages namely spatial data acquisition, integration, storage and access.

Spatial data integration involves steps 1 to 3 whereby contractors download Feature Code Libraries (FCL) from the SUE & Survey website, collect utility GPS data, and upload the data. The second stage, spatial data integration stage, involves the processing of uploaded data, checking for spatial integrity of the data, and notifying responsible personnel of any issues with the data. In addition, this stage involves loading historical or existing data into the database using the External Data Loading Tool. The third stage, spatial data storage stage, involves loading data into the utility database and performing Quality Control/Quality Assurance (QA/QC) through the Job Approval Portal (JAP). The final stage is the spatial data access described which involves access to the processed data through the Web portal and/or ESRI ArcMap.

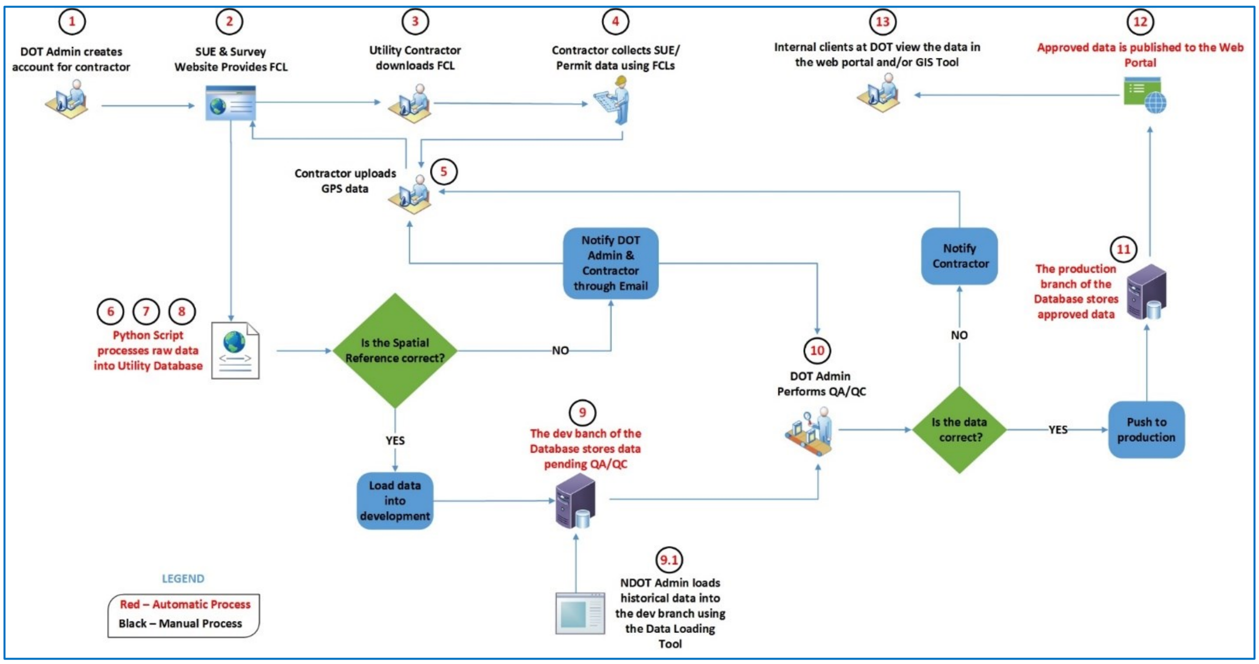

FIGURE 7. The Workflow of the End-to-End Data Management System.

CONCLUSION

There is a need for an effective management solution for big data of utilities. While other strategies and technologies may be adopted, this paper examined a case study in Nevada to demonstrate a solution involving a workflow process and software tools to manage large data for utility infrastructure. This workflow included planning, holding stakeholder meetings, creating an inventory of available data, using the right combination of software tools, incorporating national standards for Sub-surface Utility Engineering, developing a pilot project(s), data collection, database design, data conversion, implementation of a database system, and visualization tools.

In addition, management of utility infrastructure involves many business processes, including reviewing and approving permits for utility engineering companies; reviewing, storing, updating, and maintaining utility survey data; and coordinating with all stakeholders operating within the state. The complexity of these business processes requires the use of various tools and applications, including a Database Management System (DBMS), a web portal, a SUE & Survey Website, and Feature Code Libraries for surveyors.

This case demonstrates how tools and a strategic workflow process can be harnessed to develop an end-to-end management solution for large and complex data of a utility infrastructure. This end-to-end utility data management solution builds upon existing systems which are not adequate for large utility data management because they are non-scalable, do not allow for access by multiple users, involve manual data uploads, do not control consistency of data attributes, and lack visualization tools for non-GIS experts. In addition, they do not provide an end-to-end data management pipeline from data acquisition, through data integration, quality control, storage and finally to data access. The developed system in this case study was used for an end-to-end management test of large data during the testing phase and proved to perform seamlessly.

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