Anticipating Reuse: Documenting Buildings for Operations Using Web Technology

Yunsik Song, **Mark J. Clayton** and **Robert E. Johnson**
Texas A&M University, USA

This research explores the feasibility of Web technology as a means for delivering building information to better support facility operations. Our research proposes just-in-time (JIT) facility documentation as a pragmatic solution to the limitations of current as-built documents, allowing more effective reuse of building information. Our investigation addresses four issues: 1) what building information is needed for facility operations; 2) how the design and construction team can improve the format for delivering the building information to facility operators; 3) how current Web technology can store and deliver facility information in support of operations; 4) what is the mechanism of documenting building information using the Web technology.

We surveyed literature, interviewed members of design and operations teams and reviewed current initiatives of industry and software vendors to identify problems with current practices. We also surveyed promising Web technologies and conducted experiments to determine how these technologies could help to solve the problems. We constructed a conceptual framework of JIT facility documentation as a solution to current information fragmentation problems. We developed a prototype of the JIT document system to demonstrate a "proof of concept" by using current Web technologies such as Autodesk's DWF, Microsoft's Active Server Pages, VB and Java script, and Access database to develop the prototype system. By dynamically composing HTML pages in response to task-specific requests, our prototype enables easy access and integration of a variety of building information to support facility operations.

Toward a new building documentation

Architects, consultants, and facility operators from many disciplines produce information in a variety of conventional formats. As a facility evolves through its life cycle, the information necessary for efficient facility operation is often poorly structured, missing, inaccessible or incomplete (Liu, et al. 1994, Hitchcock, 1996, and Clayton, et al. 1997). As a result, it is difficult for individual operators to locate necessary facility information and understand design or construction objectives during their building operations work.

In current practice, information supplied by the design team to the facility owner is referred to as "as-built documents." As-built documents are intended to show the actual location of building systems and components after completion of a project. Designers and constructors who produce the building documents often have little awareness of the downstream uses of the information. Our previous research (Johnson et al. 1998) has identified major problems of current as-built documents such as problems with content, format, delivery, information collection and up-date. The current types of documents provided from design and construction phase are not appropriate for facility operation. We have introduced a new term, "operations documents", to distinguish more clearly from other kinds of facility documentation (Clayton, et al. 1998). While as-built or record documents are intended to document the constructed state or designed state of a facility, operations documents are intended to reuse efficiently design and construction information to support operations and maintenance.

This paper reviews recent research by ourselves and others, presents a conceptual architecture for a Web based operations document systems, and describes a "document facility for operations" process that we have used in implementing a prototype.

Information needs for operations

The operations document concept has emerged from our discussions with facility operators and managers from many different organizations to identify needs for documentation during the operations stage. The Table 1 summarizes the needs addressed by operations documents (Clayton et al., 1998).

Previous research strategies

There is very little research on issues relating to document management to support operations.

Needs	Description
Collect and filter diverse information	Building information is complex and has diverse origins. Operations information needs to be more structured and less detail.
Incorporate diverse formats of delivery information	The operations documents need to transfer and incorporate a variety of information formats into useful format for operation.
Customize information based on specific tasks	Each work task requires a different collection of information.
Include design intention	Design intent documentation is required to understand design objectives of the facility for operations.
Integrate views across functional systems	Many operations tasks require an integrated view of mechanical, electrical, controls and architectural systems.
Support training	Conceptual overviews, use scenarios, and emergency procedures must be learned by new or transferred employees.
Update information	Assuring automatic and reliable up-date procedure is crucial to long-term success of an information system for facility operations.
Usable technology	The user interfaces of an operations document information system must be familiar and easy-to-learn.

Table 1. Needs addressed by operations documents

Previous research efforts can be found in construction document management. The research in this area can be roughly divided into two approaches (Rezgui, 1995):

• The integrated document management approach (Bjork, 1993; Turk, 1994).

• The model based approach (Rezgui, 1994; Rezgui, 1998).

The integrated document management approach defines and stores document objects, indexes them by content, and supports retrieval by index. The purpose of the system is to enable easy retrieval of documents. Electronic Document Management Systems (EDMS) can be categorized in this group. Current software vendors have developed EDMS for small, mid-range to large CAD work groups and provide excellent features such as CAD document browsing, work flow management, version controls, easy customized features, and Internet connectivity etc. (Smith, 1999). These systems are becoming popular among architecture, engineering, construction and facility management (AEC/FM) organizations. These EDMS are very efficient to manage large numbers of documents in a systematic way. However, it is hard to organize information with the EDMS to establish the relationship between building product information or process and task information that is required to support the building operations and maintenance.

The model-based approach is to produce documents automatically through query of an integrated representation. In this approach, all the information in conventional drawings and text documents is stored in a single integrated database. Necessary information can be retrieved by a query, or generation of a report. Data standardization and exchange is the essential strategy to make it possible to use this approach. The strategy can be found in various research efforts such as International Standard Organization (ISO), International Alliance for Interoperability (IAI) and Tri-service CADD/GIS Technology Center. Their efforts define data models such as Building Construction Core Model (Wix et al., 1994), Industrial Foundation Class (IAI, 1996) and CADD and GIS data standards (Tri-Services, 1998) to communicate and exchange across AEC/FM disciplines and building life cycle. Little effort has yet been expended to address facility management. As Teicholz (1998) pointed out, these approaches seem to be the next generation solution in facility management. With common objects and interoperability, data will be passed across applications in a totally transparent manner. AEC/FM disciplines will share and communicate various formats of building data more efficiently. On some future, this common sharable data will be accessible through the Web. However, none of these efforts have yet been widely implemented in current practice.

The just-in-time (JIT) approach

In current facility practice, architects, consultants, and facility operators from many disciplines produce information in a wide variety of formats. One unified structure for all this information is not practical because it would require a large degree of agreement upon format, contents and responsibilities. Consequently we have adopted the strategy of an integrated document management system that exploits Web technologies to compose compound documents on-the-fly in response to the needs of specific users. Our approach provides a practical solution by collecting all the different formats of data and converting to the minimum denominator (machine readable and semi-structured format). This is a kind of transitional approach until fully exchangeable data standards are widely acceptable among the AEC/FM disciplines in the future.

Our research adopts the concept of a Just-In-Time (JIT) production system from the manufacturing field. The JIT concept is a process whose goal is to improve productivity and product quality by eliminating waste (Karmarkar, 1989). This JIT concept can be applied to operations documents for a more efficient information system. The necessary information can be produced "just-in-time" when it is needed. The production approach converts facility data into a useful information by collecting, filtering and customizing distributed facility data and infor-

Kinds of Web technologies	Examples
Web server	Internet Information Server
Web browser	Internet Explorer, Navigator
Dynamic Web publishing	HTML,ASP, DHTML, Java script, VB script, DOM, XML
Authoring tool	Front Page, Visual Interdev
Drawings on the Web	DWF, VRML
Data search and query	ODBC, JDBC, ASP, RDBMS
Redlining on drawings	Arnona Pro
Automatic feed back	E-mail, ASP
Networking	Internet, intranet, extranet

Table 2 Web technologies and tools

mation when it is needed it.

Web has become widespread and an important part of the AEC/FM industry (Froese, 1996, and Teicholz 1997). The emerging Web technologies provided an approach that is widely available, economic and platform independent. We focused our search for solutions upon the emerging Web technologies to enable the creation of JIT facility documents in a corporate intranet zone. We have developed a prototype JIT document system by implementing the documentation model. Our prototype employs Web technologies such as Autodesk's Drawing Web Format (DWF), Microsoft's Active Server Pages (ASP), Internet Information Server (IIS), Java Script, VB Script, Web browsers, Open Database Connection (ODBC) and relational databases. The Table 2 provides examples of current Web technologies available.

The diagram in the Figure 1 illustrates the three layers in our prototype system: Each layer has distinct responsibilities.

1) Distributed user interface layer: Administrators and users interfaces are distributed to their work locations. The facility operators (users) can access their necessary information through Web browsers such as Microsoft Internet Explorer or Netscape Navigator. Administrators can control and manage information through the Web browser and server interface.

There are three high levels (conceptual level) of information access routes in our prototype user interface; system-based access, task centric access, and location-based access. The different information access routes provide users alternative route information paths. At the low level (physical level), each information access actually shares the same information in a generic repository. The following provides more detailed descriptions of the information access routes:

• System-based information access: In this view, information can be accessed through building functional systems and their components, such as spatial, structural, mechanical, and electrical systems. In our prototype, we organized information in Uniformat from the Construction Standard Institute (CSI). A user can navigate the information that describes a building system and its components. The system-based access includes links across systems, such as a link from a fan-coil unit to the electrical power supply.

• Task centric information access: In this view, information can be accessed based on operational tasks. Examples of operational tasks are installation of new HVAC equipment, replacing an air filter or emergency shut down of a HVAC system. Our software collects all information necessary for a particular task into a single task.

• Location-based information access: In this view, information can be accessed based on

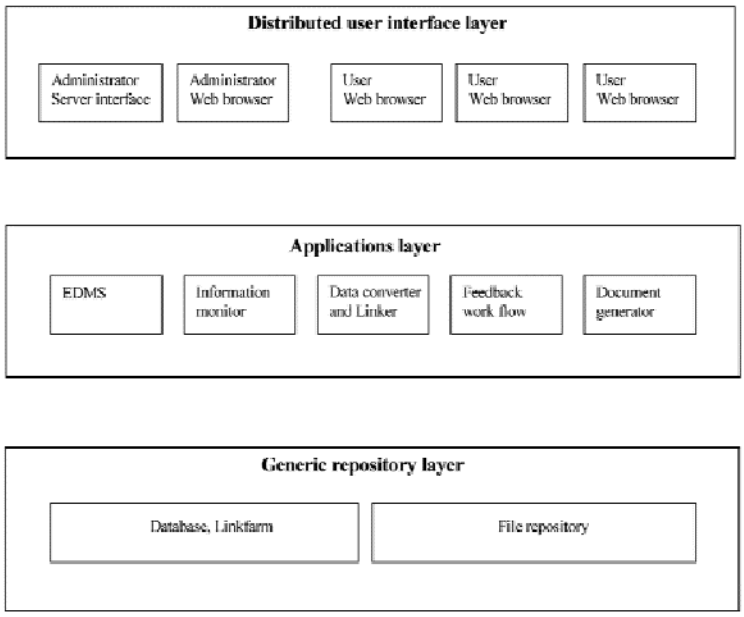


Figure 1. Prototype system diagram

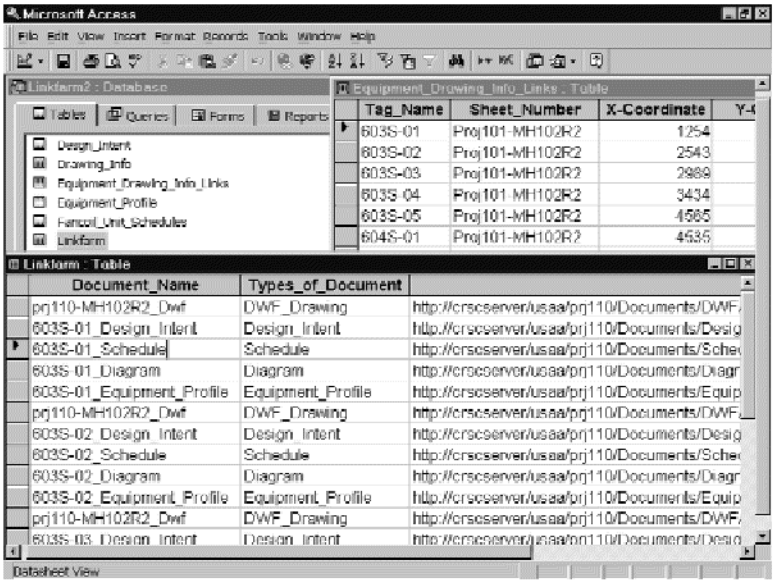


Figure 2. Example of link farm database

the vicinity of building, room, or other space location. Just like a GIS system, a user can navigate using geographical and spatial relations.

2) Applications layer: This layer contains various applications for document production and management. The EDMS application controls versions and manages documents. The data converting applications are pre-processing utilities to prepare data for storage. Web applications are used to create documents, control workflow, generate links and monitor document usage.

3) Generic repository layer: Generic repository consists of file repository and various databases such as building data, performance data, maintenance data and link farm. In the file repository, information and data are stored and organized by data format. For example, drawing information can be stored in DWG and DWF files, spreadsheet data are stored in Excel files, and text information are stored in HTML or txt file format. An additional part of the generic repository explicitly stores information about the location and interrelationships of information.

The link farm is a database that contains the physical locations of hyper-links and defines the relationships among the documents and information used to describe a building (Figure 2). The benefits of the using link farm are to manage link information efficiently, access one or more related documents through hyperlinks (Figure 3), and monitor information usage. With the link farm, all the link information can be stored and managed in a systematic way. It provides a document with one or more related information so users can easily traverse the related information through hyperlinks. The monitored information can be used for strategic information planning. The link farm concept was derived from a link management technique used in Extensive Mark up Language (XML) documents (Light 1997). XML's extended links offer the possibility of two-way or multiple-way links: "link farms" containing links within and between an entire set of documents. The link farm allows XML capable browsers to be able to traverse between simple and extended links.

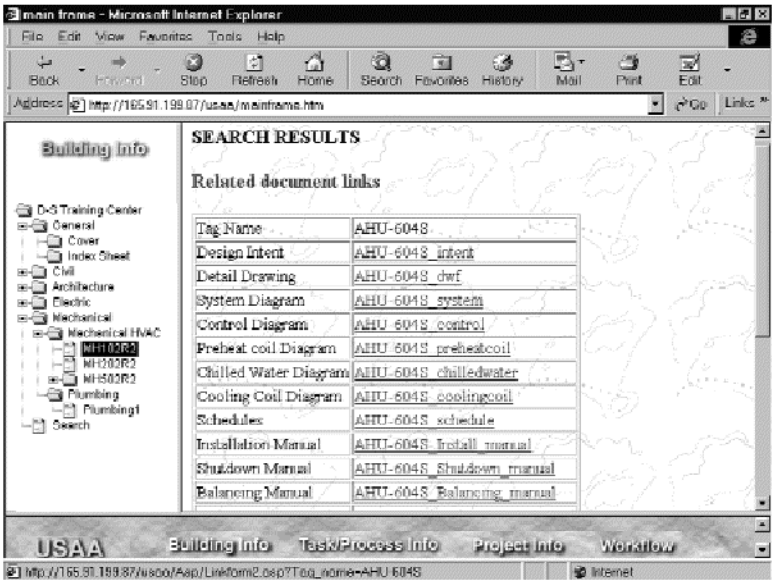


Figure 3. Example of query results from link farm

JIT DOCUMENTATION PROCESS

Our research developed an overall "document facility for operations" process (Figure5) that we have portrayed using IDEF0 (NIST, 1993). It shows the documentation process, information inputs and outputs, activities, resources and actors who are involved in the process (Figure 4). Each process can be decomposed to show further detail, as in the Figure 6. This diagram elaborates creation and retrieval of JIT documenta-

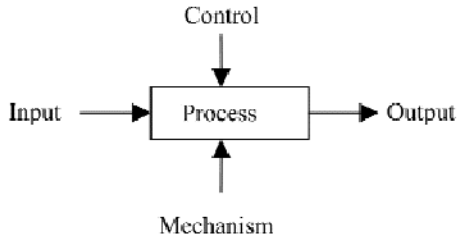


Figure 4. Schematic representation of the IDEF0 formalism

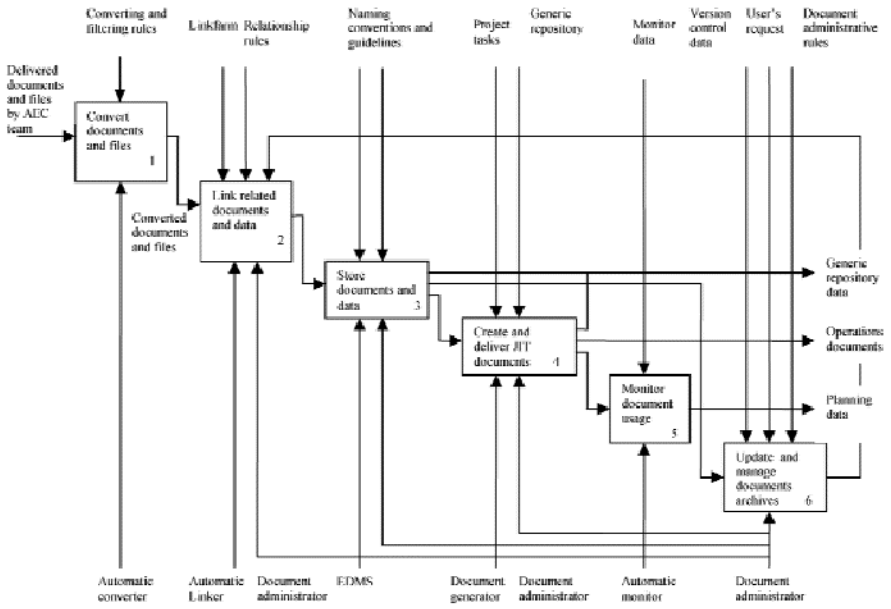


Figure 5. Document facility for operations process

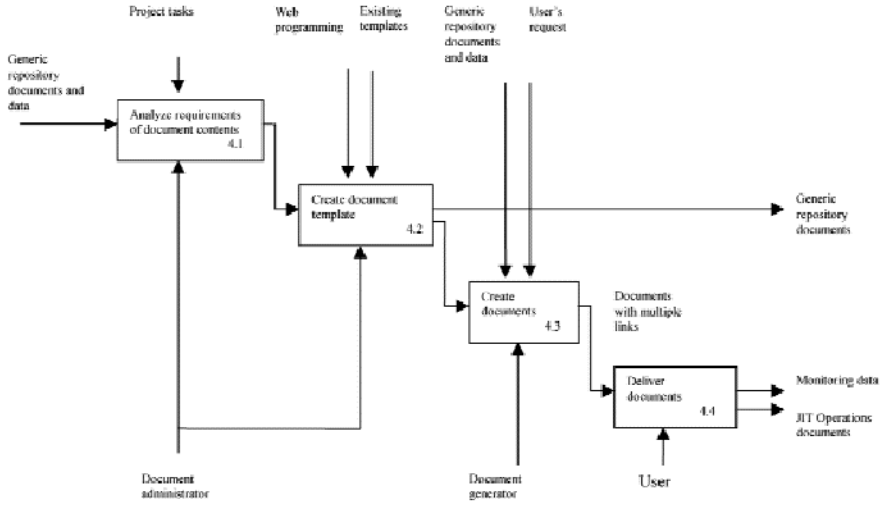


Figure 6. Create and deliver operations documents

Types of documents	Required formats and standardization
Drawings	CAD format and Web-enabled format (d.g., DWG or DWF) Sheet organization standard (e.g., Uniform Drawing System) Label names and equipment tags as provided by owner Layer standard (e.g. AIA CAD Layer Guidelines (AIA, 1997)) Embedded links on all scheduled items (e.g. mechanical equipment, electrical equipment, control devices) Use of symbols provided by owner or as suggested by Tri-Services.
Product and performance data, such as schedules and test and balance reports	Spreadsheets or databases with templates and fields provided by owner (e.g. Uniform Drawing System provides recommendations (CSI, 1997))
Equipment operation and maintenance manuals	HTML format and either Web or CD-ROM delivery PDF format if HTML format is unavailable Optical scanning if only paper based documents are available
Design intents	XML document type definitions and authoring tools
Work processes	Documentation of processes through IDEF0, pseudo code or Web scripts

Table 3. Examples of generic repository formats

tion process.

The following is a detailed description of the process implemented in our JIT prototype system as diagrammed in Figure 5 and 6. This process traces information from its delivery by designers and contractors, through its incorporation into the operations document system, and finally delivery to the line personnel responsible for maintenance and repair.

Convert documents and files

The formats of documents delivered by the architect, engineer, contractor, and subcontractor are usually different from each other. This inconsistent information structure creates an obstacle for efficient facility operation. In our case study, product data and performance data are in paper formats, schedules are included in record drawings and operations procedures and design intents are in hand-written notes and e-mail messages. We suggested that information be collected and stored as specified in the Table 3. The process of adopting and converting externally generated information can be done in house by running conversion software. Design and construction teams could also deliver the information in the desired format out of contractual obligation. For our prototype, for example, we extracted HVAC equipment attributes data from an AutoCAD drawing, converted it to an Excel spreadsheet format. This converting process can be automated with AutoLisp or Visual BASIC programming in AutoCAD.

Link related documents and data

Once documents are converted to a machine readable and standardized format, necessary related links can be generated. The link process can be done semi-automatically with link generator. For example, we embedded hyper-links into drawing files using an AutoLisp program in AutoCAD. We also made necessary information

links based on operations tasks (see section 4.1 Analyze operations tasks for more details). All the necessary link data was stored in a Microsoft Access relational database.

Store documents and data into a generic repository

The JIT document production process can be optimized by using standard formats; such as templates, symbol libraries, naming and classification systems for labeling, drawings and diagrams; predefined digital formats for tabular data; and text format for design rationale. Previous research (Clayton, et al., 1999) has identified possible conversion formats for storing data into generic repositories. The Table 3 describes some of the examples.

Create JIT documents

In our prototype, a document generator creates JIT documents on the fly. The document generator automatically generates JIT documents based on the predefined task templates which reflected the information needs of an operations task. The Figure 6 diagram illustrates in detail the JIT document creation process as follows:

Analyze operations task: Analyzing an operations task is the key to identify necessary information to perform the task. Defining a specific task determines information needs and an information access route. An operations task, for example installing a new fancoil unit might need a task schedule, record drawings of the fancoil units, operations procedures and current test and balance reports. This task analysis process can be done by a task analyst or administrator. The analyst or administrator can create and document the task analysis with process diagrams such as IDEF0.

Create documents templates: A document template provides a predefined format and content for a JIT document. In our prototype the document generator uses a task centric template, which collects, filters, customizes and retrieves necessary information in real time based on the specific operations tasks. The task template incorporates various kinds of information formats such as text, drawings, diagrams, spreadsheet, tables, and multimedia formats such as video and audio. In our prototype, the task-centric templates have been created with ASP in conjunction with Java Script and VB Script.

Create JIT documents: The predefined templates generate HTML documents on the fly by querying the link farm for the needed link targets. A script retrieves records from a database, drawing files, diagrams, images, text and many other kinds of data formats and dynamically generates a concise document on demand of a user's request (Figure 7). The example in the Figure 8 demonstrates a JIT installation document that includes design intent, system diagram, and physical data to perform an installation task of specific fancoil unit (e.g., tag number 604S-02).

Deliver document: A user can view JIT document as a HTML file on the screen or can print the document for his record. A JIT document can also provide one or many links to other related documents from link farm. The User can retrieve these related documents from the JIT document. Information and data such as design information, product data, performance data, maintenance data are gathered and transformed to a specific operations document such as an installation manual, shutdown manual, operations procedures, or training manual.

Monitor document usage

Each retrieved document is monitored automatically by the system (Figure 9). An information manager can use this data to make decisions about the importance of various kinds of building information. This data includes documents retrieved, the user's browser location, and time of uses. In our prototype we created the monitor module with ASP and stored the monitored data automatically into a Microsoft Access database.

Update and manage document archives

Current Electronic Document Management System (EDMS) such as ACS software's AutoEDMS, Cyco's AutoManager WorkFlow, or

Motiva Software's DesignGroup etc., can be used to help keep documents up-to-date. These EDMS products support the management of various document formats such as CAD, text, and spreadsheets etc., as well as Internet and database connectivity, and workflow support. In our prototype, administrators and users can send work reports, notices, and feedback directly to the specified individuals as e-mail to report or update information. The work reports are important to describe the state or results of an operation. Notices can be sent automatically to people who are affected by shutdown or emergency operations. The workflow incorporates predefined forms and e-mail. In particular, feedback includes graphic information to direct the modification of drawings to reflect field conditions. Our prototype has employed CADViewer by ArNoNa Internet Software Inc., an electronic redlining tool written in Java that works with the DWF format (ArNoNa 1998). Mark-ups can be made to a DWF file and then saved as a separate file. In a just-in-time operations document system, the mark-up files, updated databases, and messages to the document maintenance staff serves as feedback by which documents are kept up to date.

The limitations of the system

Implementation of our prototype system will not be successful unless people rethink and reorganize the building process throughout its lifecycle. Collecting and storing information in the minimum required format as shown in the example in the Table 3 might require extra responsibilities and expense. The process of capturing design intention, and creating simplified drawings and diagrams depends upon resources of personnel and training. These all need some degree of agreements and consent among building owners and AEC/FM participants prior to implement our system. An information administrator's role has to be redefined for our system. The information administrators are actively involved in collecting and storing information in a certain format, analyzing and creating task template, managing link farm, monitoring information uses and feedback for information update. The role of the information administrator is very important. Some of our suggested process such as converting information format, linking and monitoring information can be automated, but the other process such as analyze task, create task template, and manage link farm rely on manual methods in our prototype system. Some of this process may be automated in the future.

Conclusion and future direction

Our research has introduced and demonstrated JIT operations documents as a practical solution to the problems of current as-built documentation in order to support facility operation. The JIT documentation process presents how design and construction information can be reused for facility operations. The benefits of using our prototype system are expected to the following:

Deliver necessary and concise information for operations: Our prototype system delivers necessary information based on the results of task analysis to perform an efficient operations task. Our prototype system delivers concise information on demand by incorporating diverse formats of information and filtering and customizing information.

Easy access to related information: The Web-based interface is a familiar and powerful way to locate and retrieve needed information. The three access routes accommodate a variety of needs and access styles.

Eliminate duplicated information and reduce re-creation time: Our system reuses design and construction information and eliminates duplicated information to create operations, maintenance and training documents. It also reduces re-creation time.

Reduce training time and efforts: It provides on site just in time training information. A user can learn how to operate building systems and components on site. The system-based access route is a useful way to browse the information and learn about the various systems.

Provide better update and reliability of information: Our prototype system provides an automatic workflow mechanism and redlining tool for updating and managing information effi-

ciently.

Provide quality assurance of information: Our prototype system monitors information usage and utilizes this information for strategic information planning.

We demonstrated our prototype to operations personnel at United Services Automobile Association (USAA). Our discussions with them, their feedback and our initial experiment of the prototype system led us to conclude that this system might be a practical and efficient way of delivering and managing information for their daily operations work. A thorough empirical test of the prototype system can produce evidence regarding the expected benefits listed above. Monitoring information in a link farm, cost benefit analysis and subjective evaluation by operations personnel will guide us in the future development of the system.

Continuous investigation of new technologies is necessary since information technologies are changing and emerging so rapidly. Technologies such as common product and process model and XML are still developing and promise many potential uses for facility operations documentation. We are planning to participate in industry standards initiatives and investigate the use of the common product and process models and objects for facility documentation. Currently we are also exploring the use of XML as a medium for recording design rationale. The XML design rationale document will be used to create operations manuals, maintenance manuals, training manuals, troubleshooting and redesign. Documenting design rationale is essential to understand design objectives of building systems and components for facility operations and maintenance.

Acknowledgement

This research has conducted in collaboration with the facility operations department of USAA, and CRS Center at Texas A&M University. We have focused on an in-depth study of mechanical, electrical and plumbing (MEP) building systems.

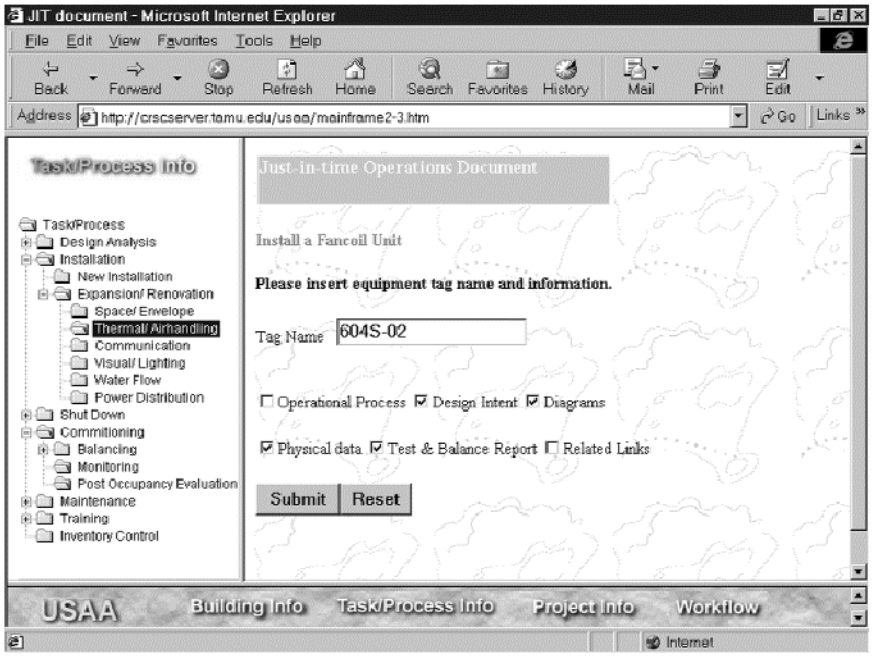


Figure 7. Example of JIT document query

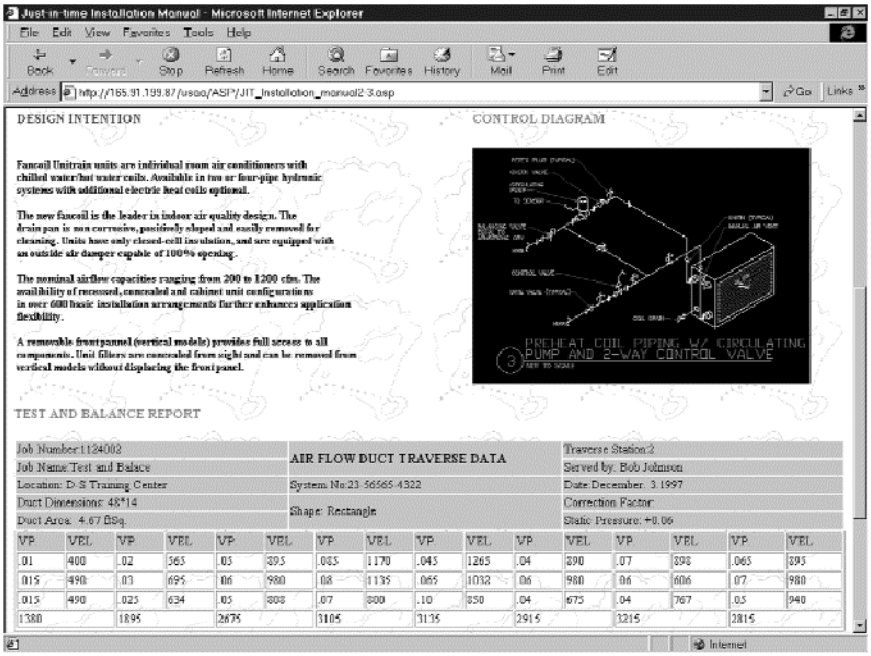
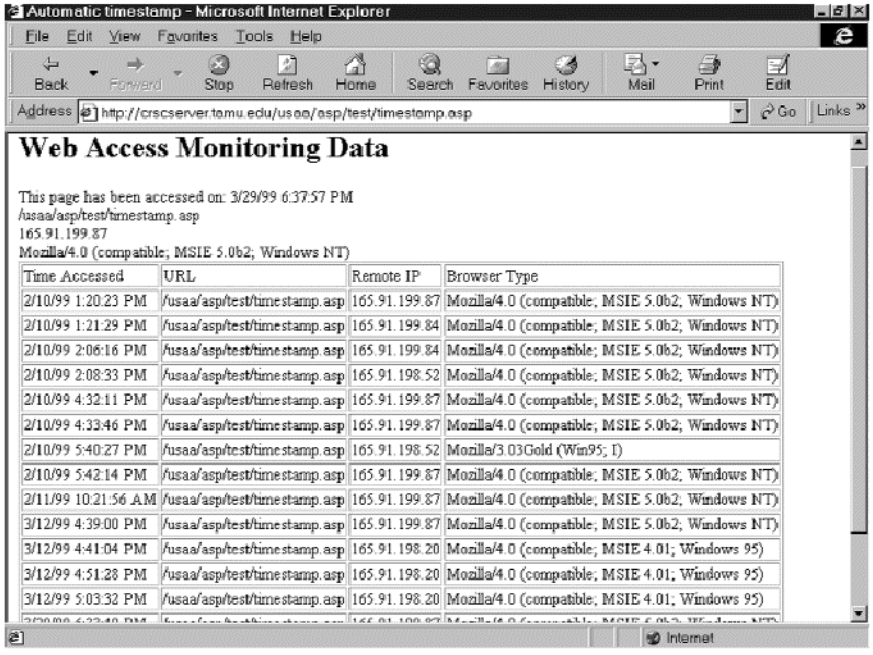


Figure 8. Example of JIT document



Time Accessed	URL	Remote IP	Browser Type
2/10/99 1:20:23 PM	/usaa/asp/test/timestamp.asp	165.91.199.87	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
2/10/99 1:21:29 PM	/usaa/asp/test/timestamp.asp	165.91.199.84	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
2/10/99 2:06:16 PM	/usaa/asp/test/timestamp.asp	165.91.199.84	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
2/10/99 2:08:33 PM	/usaa/asp/test/timestamp.asp	165.91.198.52	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
2/10/99 4:32:11 PM	/usaa/asp/test/timestamp.asp	165.91.199.87	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
2/10/99 4:33:46 PM	/usaa/asp/test/timestamp.asp	165.91.199.87	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
2/10/99 5:40:27 PM	/usaa/asp/test/timestamp.asp	165.91.198.52	Mozilla/3.03Gold (Win95; I)
2/10/99 5:42:14 PM	/usaa/asp/test/timestamp.asp	165.91.199.87	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
2/11/99 10:21:56 AM	/usaa/asp/test/timestamp.asp	165.91.199.87	Mozilla/4.0 (compatible; MSIE 5.0b2; Windows NT)
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3/12/99 4:41:04 PM	/usaa/asp/test/timestamp.asp	165.91.198.20	Mozilla/4.0 (compatible; MSIE 4.01; Windows 95)
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3/12/99 5:03:32 PM	/usaa/asp/test/timestamp.asp	165.91.198.20	Mozilla/4.0 (compatible; MSIE 4.01; Windows 95)

Figure 9. Example of monitoring data

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