Results of CSCW Supported Collaborative GIS Data Production: An Internet-based Solution

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ABSTRACT

The principles and technologies of computer supported cooperative work (CSCW) are increasingly integrated in many areas to support distributed collaborative production, especially with the rapid growth of the Internet and broadband network technologies. To achieve the improved efficiency and productivity, group processes and interaction must be properly addressed and the design of supporting computer systems must be thoroughly studied. These usually vary from one area to another depending on the understanding of the surroundings of the needed computer system through modeling its business environments. However, the documented work indicates little evidence of applying such an integrated solution to the challenges found in management of GIS data production.

This paper summarizes the results of research and development towards Internet-based support of collaborative GIS data production, and discusses key issues in applying CSCW technologies in distributed GIS data production environments. The results indicate that GIS, Internet, Groupware, and Data Warehousing principles can be effectively brought together and applied to provide better solutions to real-world challenges associated with project management and quality control. The results also show that the integrated solutions can be used to effectively facilitate collaborative GIS data production processes in a distributed work environment if a *"sound"* collaboration model of the work environments is in place.
Key Words: GIS, Data Production, Internet, CSCW, and Collaborative

1 Introduction

The Internet-based computer supported cooperative work (CSCW) concepts and related technologies have been increasingly integrated in many areas to support collaborative production in distributed work environments, through which collaboration among group of people located at various geographical locations can be realized. GIS data production is among these potential areas, particularly when data production contracts involve several teams at different locations.

The adoption of CSCW concepts and its technologies to facilitate spatial decision making processes among people from different locations at various levels has been a focused development in integrating CSCW and GIS for the last few years. Some simple forms of informal use of CSCW, such as email and FTP of GIS data files, have also been found in GIS data production work environments. Few GIS/mapping firms, however, have adopted formal strategies of applying CSCW systematically to support their data production workflow and related project management. This is mainly because of:: (1) the lack of formal understanding of collaboration characteristics of GIS data production projects; (2) the high cost of supporting infrastructure required; (3) the social/technical uncertainties of CSCW software implementation; and (4) management concerns over the potential costs involved in reengineering existing business processes.

GIS and mapping organizations have been driven by emerging technologies and expanded markets, shifting from traditional data production techniques to digital mapping and geographical information systems [Coleman and McLaughlin, 1988]. The corresponding business goals in the service sector have shifted from purely providing high-quality data products to providing "total customer satisfaction" [Manheim, 1998]. This requires not only the change in the underlying work environments, but also in the supporting technologies involved. The Canadian GIS data conversion industry of the 1980's was dominated by a few large surveying or mapping firms, where each company largely maintained the in-house expertise and software/hardware facilities required by data production processes. Overall data production – from field data collection/conversion and original production through inspection, correction, initial distribution and recurrent updating – was traditionally designed in an environment where work was completed in a single location and complete sets of data materials were shipped in bulk from one unit to another -- usually in the same building [Coleman and Brooks, 1996].

Regardless, the whole process remained sequential in nature and contained many potential instances of "bottlenecks" that may delay the final delivery of data products to customers [Coleman and McLaughlin, 1988].

Due to trends of deregulation, outsourcing and downsizing of organizations, today's geomatics industry is characterized by a greater number of smaller, more specialized GIS/mapping firms attempting to satisfy increasing customer demand for fast-delivered and high-quality GIS data. At the same time, it has been increasingly difficult for government mapping agencies to maintain in-house expertise and resources to fulfill their mandates of providing timely and high-quality GIS and mapping data. It has, therefore, increasingly become common practices for government agencies to outsource GIS data production tasks and for one or more geomatics firms to contract the whole or part of the data production responsibility on both program or project basis ([Sebert, 1989]; [Sabourin, 1994]; [Coleman and Brooks, 1996]; [Rejean, 1999]).

This contract-based production (CBP) model utilizing consortia of data production companies and government agencies has been explored and increasingly become prevalent within geomatics industry since the mid-1980s [Coleman and Brooks, 1996]. One of the notable advantages of the CBP model is the inclusion of a separate contractor serving as data quality inspector whose responsibility is to assure all produced data satisfying specified quality standard on behalf of the customer, while issues related to project communications and activity coordination remain problematic. The practical use of this production model has been adopted in Canada to handle provincial mapping programs in British Columbia, Alberta, Ontario, and Quebec, as well as at the federal level through Geomatics Canada, among several other countries.

The recent progress of computer-supported cooperative work (CSCW) in supporting distributed applications has been greatly fostered by the rapid development of high-speed Internet services and Internet-based client/server technologies. CSCW has brought with it investigations into interactions between individuals in a group through coordinated actions, shared workspaces and group awareness of work related information and presence of other group members. "Groupware" packages have been developed and, in some cases, been extensively redesigned to support Internet or Web based applications. The major capabilities these groupware packages provide include:

1. Informal and formal sharing and dissemination of many types of information;
2. Collaborative viewing, editing and manipulating shared objects (in both asynchronous and synchronous modes);
3. Real-time communications (conferencing and electronic meeting); and
4. Workflow process management.

These developments have already enhanced GIS related applications through the growing use of the Internet to handle spatial information — hosting web sites, sending e-mails, transferring small digital data files between GIS data production offices and, in some cases, enabling group-based spatial decision-making with CSCW technologies. Introduction of integrated Internet-based CSCW solutions with existing GIS installations may hold great potential for resolving many of the issues faced by GIS data production contracts and open many new opportunities for managing these projects more efficiently and effectively.

2 Defining Collaborative GIS Data Production

This particular research examines the potential for effective integration of CSCW technologies into "collaborative GIS data production" work environments.

2.1 Collaborative GIS Data Production

The concept of "collaborative production" has been applied in many areas to support various distributed work environments involving multi-parties, such as collaborative manufacturing [Poltrock and Engelbeck, 1997], collaborative CAD/CAM design [Kao and Lin, 1998] and collaborative product development [Bruce et. al, 1995], among others. The information technologies involved in supporting these collaborative production efforts include CSCW technologies, computer networking (especially the Internet in the last few years) and domain-specialized software packages such as AutoCAD.

In geomatics, the first formal discussion on this concept was from an internal workshop, called "ChartNet Workshop on Collaborative Production", which gathered many experts from Canadian geomatics area to provide inputs for the Canadian Hydrographic Service and Nautical Data International (Ottawa, Canada) in support of a CANARIE-funded project on application of broadband networks to electronic chart production [Coleman, 1994b]. Although no final definition was derived from that workshop, the workshop participants did provide valuable insights on required supporting technologies for and needed capabilities by collaborative map and chart production environments.

While human-computer interaction principles are applied as fundamentals for interface design, both artificial intelligence and digital library techniques are also considered as keys for implementing a "smart", information-rich collaboration environment [Favreau and Mills, 1996]. As such, "collaborative production" has been considered not just a label but a distributed work environment that encompasses people, organizations, computer networks, production processes, supporting technologies, and suitable management policies.

Geomatics firms rely heavily on GIS and image processing software for many of their core business functions [Finley and Coleman, 1999]. While network-capable GIS software such as ArcInfo ™ and CARIS for Windows ™ has been available for many years to allow users share the same geographic data and GIS functions, it has not been developed to the point where users can communicate with each other simultaneously using the same function through GIS servers. In addition, it has always been assumed that users will employ the same operating systems and platforms. Recent developments of more advanced Internet-based GIS technologies and standards (e.g., Open Geospatial Data Interface - OGDI from Global Geomatics Inc. and OpenGIS Abstract Specification from Open GIS Consortium) help overcome this system incompatibility problem to some extent. However, when project participants in data production environments adopt different GIS software and computer platforms, software incompatibility issues will still cause significant problems at the data quality control stage [Finley and Coleman, 1999].

Issues regarding how CSCW technologies can be formally applied to support GIS communication, collaboration and coordination (3C) needs have not been well addressed in GIS communities. Some early efforts investigating the use of CSCW technologies to support collaborative GIS data production revealed the need of GIS-compatible CSCW tools and the need to apply formal workflow modeling and management tools in improving data production efficiency and productivity [Coleman and Li, 1999]. Favreau and Mills [1996] discussed several key technologies for supporting a global collaboration infrastructure and Finley [1997] identified information technology needs for geomatics firms. In summary, the technology requirements to support collaborative GIS data production include the following:

(1) *High-performance Networking Infrastructure*: High-speed networking provides the underlying infrastructure that brings participating firms together in a restructured fashion [Finley, 1997] and enables project information and GIS data materials to move quickly and reliably across collaborative production environments.
(2) *Database Technology*: Databases serve as data warehouses for both project information (e.g., project metadata) and GIS data management. Online databases techniques such as online analytical analysis process (OLAP) and online transaction process (OLTP) may provide necessary support. In the long run, when GIS data in production is stored and managed in spatial databases, the spatial data warehousing and spatial OLAP may be required [Rivest et al., 2002].
(3) *GIS and Mapping Techniques*: GIS software and mapping tools are necessary to perform actual data acquisition, conversion, editing and quality control tasks.
(4) *CSCW Technology*: This technology supports both formal and informal collaborations among participants. It can also provide support for controlling and automating production procedures, as well as coordinating project activities to control the overall progress.

With the support of these technologies, it is possible to develop a virtual collaborative environment that supports collaborative data production efforts. While the collaborative data production environments contain both organizational and technical aspects, it is its technical side that this research project focuses on.

2.2 Collaborative Workspace

A computer-supported virtual environment provides technological support for collaborative production. This distributed collaborative workspace can be described as a shared project workspace that uses shared databases, a set of collaboration functions, and collection of digital data files, and permits definition of group members' roles, project status reporting & tracking, and gateways to electronic mail and other sources of data. Such a workspace should also permit the organization of correspondence, comments; reports, etc. associated with a project or product and should support the management of multiple versions of objects [Coleman and Brooks, 1996]. From users' perspective, the workspace provides access to all project-related information they are authorized to share, personal worklist containing all tasks assigned to them, and collaboration functions they can use to collaborate and communicate with other participants.

The development of such a collaborative workspace largely depends on a comprehensive understanding of the collaboration characteristics of the CBP-based GIS data production practices. In addition, hardware, software and operational constraints to online project management procedures have to be well identified to facilitate the implementation of such collaborative workspaces. More importantly, GIS data production tasks involved in the workspace have to be investigated with respect to the level of needed network connection speed. To date, however, research effort on this respect has been limited to conducting feasibility studies of CSCW, preliminary investigation of existing data production projects, and evaluation of currently available groupware systems ([Finley, 1997]; [Boettcher, 1999]; and [Coleman and Li, 2000]).

While the software implementation of such a collaborative workspace may be relatively easy to realize to provide required functional support, the ultimate adoption of it to support distributed GIS data production projects will remain uncertain unless it can be proved that the proposed solutions provide shortened "production float", streamlined or alternative data production procedures, and improved communications channels.

2.3 Problems to Be Solved

GIS data production projects organized based on the CBP model may be conducted successfully in terms of improved data quality, faster project turnaround time, or improved productivity if: (1) all project related data materials can be transferred in a timely manner; (2) project information and issues (e.g., specification ambiguities) are well communicated; and (3) all production processes are under control. However, these assumptions are often compromised by the following issues identified from the existing data production projects due to the multi-party and multi-location nature of the CBP model:

1. Time consuming or unreliable approaches of transferring data and other production-related materials among project participating work sites during production processes;
2. Lack of efficient communications channels for distributed participants to discuss technical and managerial problems;
3. Difficulties in efficiently and dynamically controlling project progress and tracking status of data files and production process activities; and
4. Lack of efficient management of the production-related reports, comments and correspondences, which may be used as project memory for future reference.

While the on-time delivery of customer specified digital data may be ensured by resolving the above issues, there are other project management issues. In particular, GIS data production normally involves many rounds of data file submission and resubmission due to possible failures of some data files in passing quality control (QC) inspections. Therefore, project managers often face the following three important challenges in managing CBP-based projects:

1. How to manage multiple production contractors including sub contractors and data quality control inspectors involved?
2. How to manage multiple contractor submissions and resubmission to ensure that all involved data files are kept with proper identifications, e.g. version controlled? and
3. How to reduce duplications of effort and waste of both project and system resources?

Although all above issues and challenges must be addressed to ensure the success of CBP projects, the biggest concerns are the communications of the project status, problems and progress and the transfer of large digital data files consisting of very large datasets – often up to 85 megabytes for graphical files and 200 megabytes for image files. Project deliveries could be delayed due to uninformed updating of data specifications or long time and risk of data loss associated with transferring data files over current postal services. More importantly, the different interpretations of the specifications and lack of common understandings of quality requirements may result in more data files failed to pass data QC processes. The development of the Internet-based solution aims at solving the above problems to certain extent by integrating CSCW technologies and Internet within existing GIS data production environments, focusing on production process control and project management tasks.

3 Research Outcomes

The principal research objective of the project was to verify whether or not an Internet-based model of collaborative production could provide sound performance for improving distributed GIS production operations and project management. To investigate this, an integrated collaboration model prototype — including a workflow model, an architecture model, and an implementation framework — was designed, and specific strategic components of this prototype were then developed and tested. The following sections summarize major research outcomes.

3.1 Specifications of Collaboration Requirements

The design and development of the collaboration model largely depend on a comprehensive understanding of the existing GIS data production environments and project practices based on the contract-based production model. To accomplish this, the unified modeling language (UML) was used to model existing project processes and to capture and specify collaboration requirements necessary for supporting collaborative GIS data production. While the modeling effort was made in a process-centric approach (Figure 1), the caption and specification of collaboration requirements was system-oriented and focused on the functional and non-functional requirements of the proposed collaborative workspace.

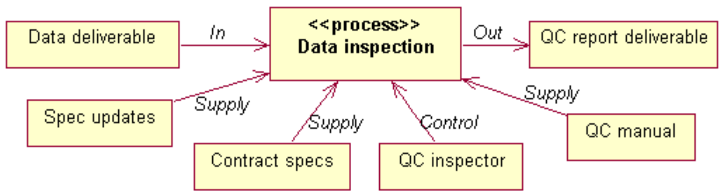
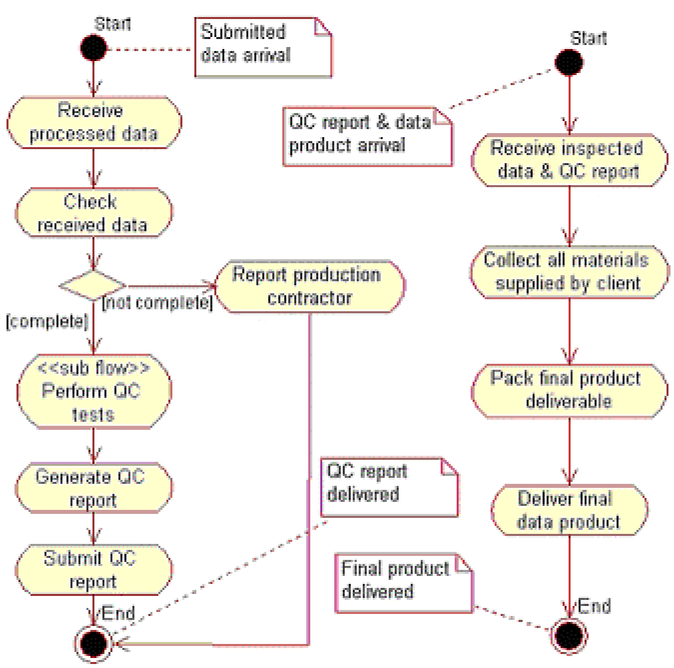


Figure 1 Process-centric Modeling of Process Resources

To ensure the in-depth understanding of existing GIS data production practices, the research team met with several private companies and government organizations in order to collect many sample forms, work sheets, procedures, and relevant project documentation. Outputs from this stage of the research include a set of UML activity and class diagrams capturing management and production processes (see example in

Figure 2). As well, the associated process resources and requirements related to more than a dozen specific collaborative production functions or processes were developed and documented (
Figure **3**). However, non-functional requirements are not always described within use cases. The collaboration requirements were further verified with a brief review study of several major groupware packages and gaps between the required functionality and available functions are identified. These outcomes provide a sufficient and solid foundation for the design and development of the collaboration model.



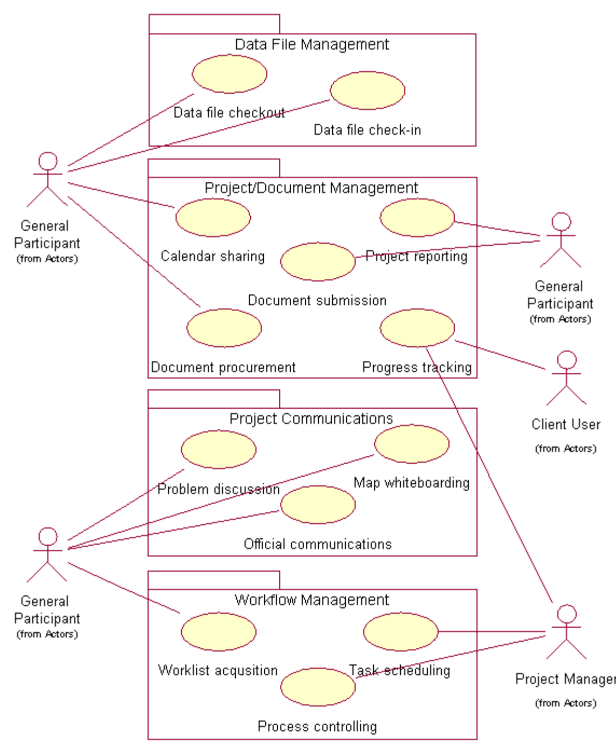


Figure 2 Modeling the Data QC Process

Figure 3 Modeling Functional Requirements

3.2 Development of Collaboration Model

The collaboration model was developed based on the identified collaboration requirements and process modeling, verified by the research prototype development and then refined based on the prototyping results. UML and workflow process definition language (WPDL) were used as much as possible to ensure the clear representation of the designed model. The rest of this section summarizes the accomplished components (sub-models) of the developed model.

The Workflow Model provides a process view of the collaborative workspace. To ensure the lasting value and generality of this sub-model, the workflow reference model (WRM) and its interface specifications from WfMC [1995 and 1999] was carefully studied and a hierarchical structure of workflow process repository was developed as illustrated in Figure 4. UML and WPDL artifacts were created to presented model instances both graphically and textually. The model characterizes existing GIS data production processes with respect to organization structures, invoked applications, and data model, especially the concept of including a QC testing program repository was presented (**Error! Reference source not found.** and **Error! Reference source not found.**).

The Architectural Model offers a structural view of the collaboration workspace. To ensure component-based structure of the collaborative workspace, the overall logic architecture was designed at higher level into three separate but linked layers, i.e. presentation layer, business logic layer and data access layer (Figure 5). The presentation layer contains IICW interfaces which can be web-based, stand-alone, or API to ensure wide suitability. The overall architecture was then populated on each layer with most significant components which satisfy identified functional requirements.

The Implementation Framework describes a five-step "*technology driven*" process for implementing the collaborative workspace based on the designed workflow and architectural model. In order to design a more feasible framework, the effort was made to incorporate lessons learned from existing CSCW application implementation practices and problems encountered during design and development stages of the proposed collaborating systems. The framework illustrated in **Error! Reference source not found.** contains major technical milestones in implementing a collaborative workspace.

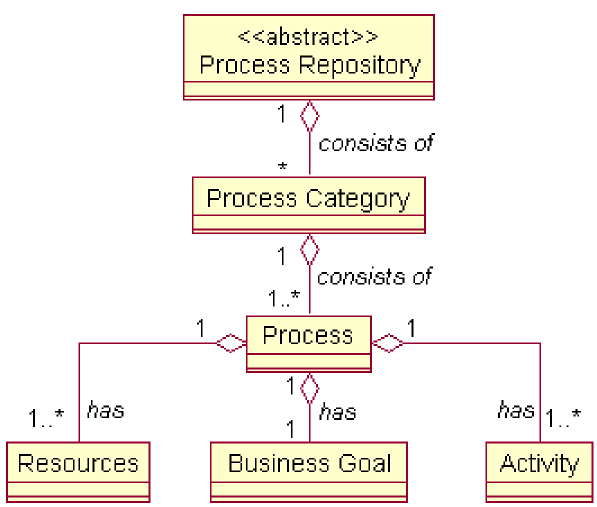


Figure 4 Hierarchy of Process Repository

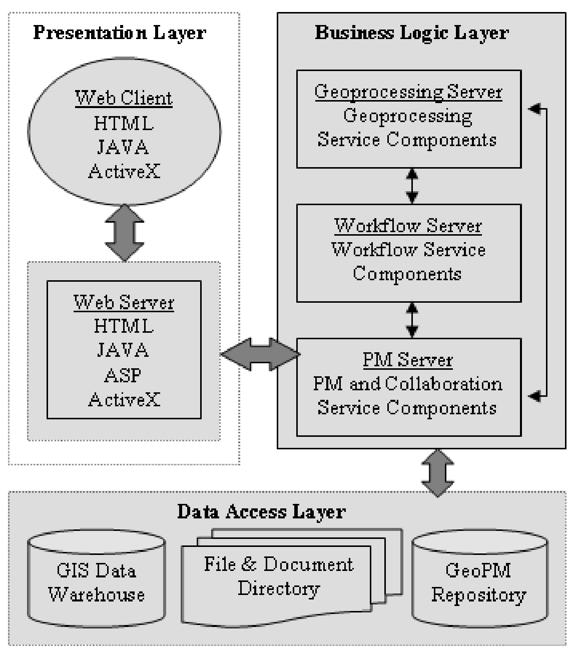


Figure 5 Architectural Model of the Workspace

3.3 Implementation of Prototype Collaborative Workspace

A combination of software components and stand-alone systems was used and integrated into the prototype system. To select necessary software components or systems appropriate to the prototype development, a large number of groupware components, workflow systems, and GIS toolkits were examined and (in selected cases) were assessed based on the available evaluation versions. While extensive product searches were undertaken, it proved to be extremely difficult and problematic to find: (1) suitable workflow management system software; and (2) software components that did not reply on any commercial systems and could be easily programmed into the collaborative workspace.

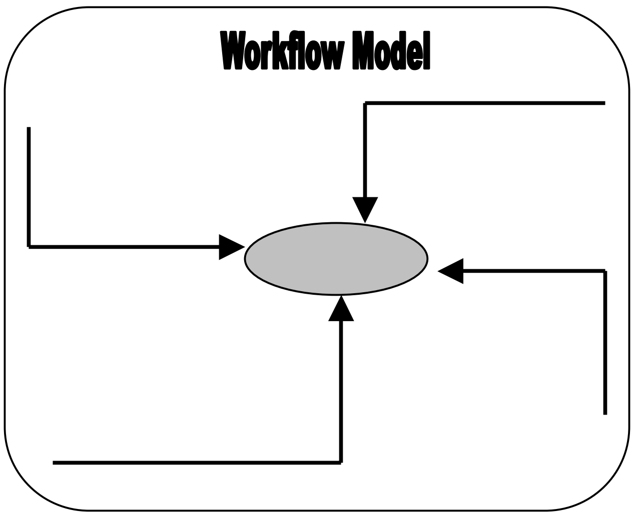


Figure 6 Composition of Workflow Model

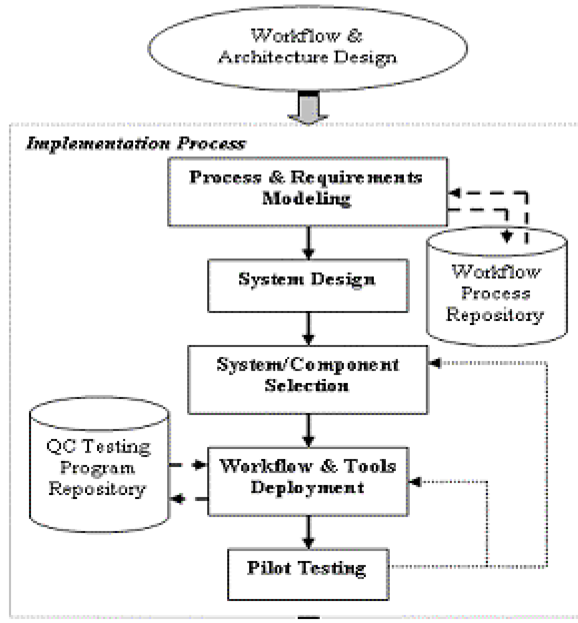


Figure 7 Implementation Framework

Figure 6 shows the system configuration of the collaborative workspace prototype. The developed prototype provides a total of 12 major functions. To integrate or develop these required functions, a substantial amount of programming work was completed using Visual Basic, Java, and PL/SQL languages. The other major effort made was to learn, install, configure and manage the selected software systems supporting the prototype, such as Oracle Database and Workflow systems. Although this type of work is not trivial for the research project, it has been proved an excellent learning experience for future work and research in the relevant areas.

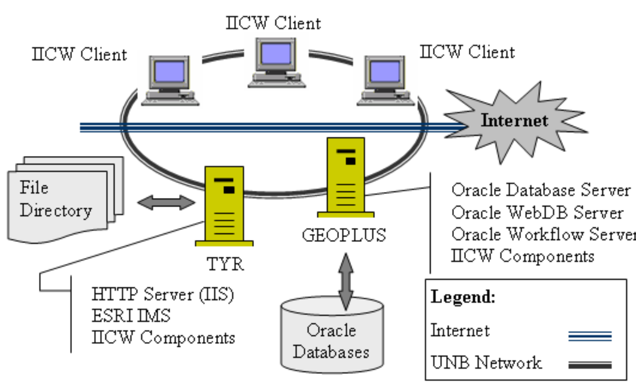


Figure 6 System Configuration of the Prototype Workspace

Developing a collaborating system to support project management and operations in distributed GIS data production work environments is a huge task requiring extensive research. This is not only because of the design and implementation complexity of CSCW and groupware tools in real-world applications but also due to multi-participation nature of involved projects. The incremental approach of adding functional components adopted has been verified as an efficient way in prototype development.

3.3 Process Performance Analysis

The process performance is compared against a typical paper-based manual QC inspection process (non-CSCW supported process). It is important to note that the comparison here is between processes only and not technologies since the supporting technologies in this context are only tools to facilitate process gains. The comparison is generally conducted to determine three categories of benefits as discussed in Baeza-Yates and Pino [1997]: *improved outcomes*, *individual and group gains*, and *efficiency*. While the first two groups of benefits are difficult to measure in this research due to the lack of testing data from real world projects, the efficiency is measured based on a number of performance metrics including duration, elapsed time and resources required for every isolated workflow tasks. The resources are measured as capitalized costs of involved process workers, consumed materials, and supporting hardware and software shares. The duration and elapsed time are measured in days and cost is estimated as dollar values. To make the comparison easy, all measurements of performance metrics are converted to the equivalent of the amount required by processing the same number of data files.

The compared workflow tasks are isolated from the implemented QC workflow process as illustrated in Figure 7. Since the Oracle Workflow uses a notification mechanism to execute its workflows, most of the workflow tasks are notified to the workflow performers and are completed “off-line” (i.e. not controlled by the workflow), except those automatically executed tasks. For example, when the QC inspector is notified of some data files to be inspected, the inspector will check out these data files and inspect them off-line in the same way the paper-based QC process does. In this sense, there is no need to compare the performance metrics for actual inspection work.

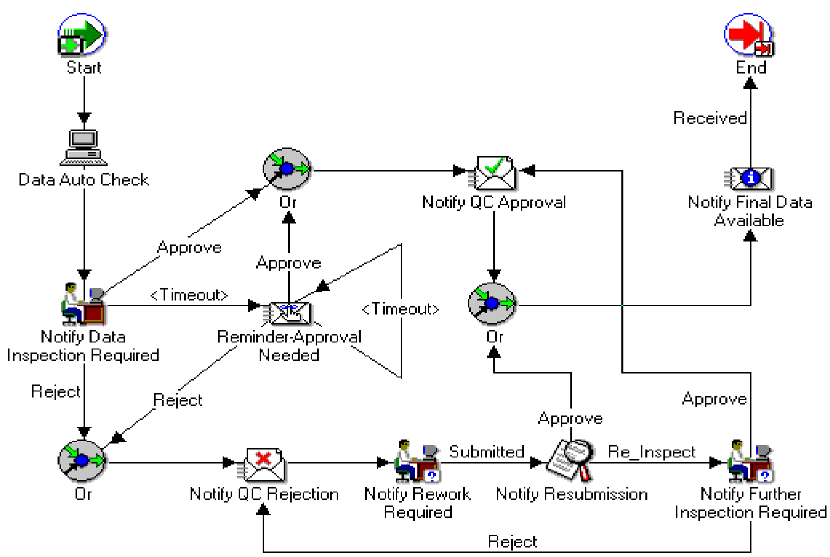


Figure 7 Data Quality Control Workflow Process Defined with the Oracle Workflow

The performance analysis results summarized in Table 1 indicate a substantial potential time savings offered by the introduction of the collaborative processes offered by the GeoPM collaborative prototype. As well, this overall improvement in turnaround time compared with traditional project workflow is even more dramatic in cases where data shipments require further checks before resubmission. Other more intangible improvements – such as those related to more efficient sharing of documents and updates to specifications— nevertheless should contribute positively to reduced learning curve, faster turnaround times, higher-quality product submissions, and fewer reworks as well.

4 Discussion of Results

The work presented in this paper represents a new approach for supporting distributed GIS data production project management and operations. The total reduction in turnaround time (based on the difference of elapsed times) introduced by the proposed approach within the life cycle of the tested QC process is about 60%. Since testing was performed in a simulated work environment rather than on a real project, exact time savings and cost effectiveness could not be assessed.

However, the authors maintain that savings in labor costs, shipping, and turnaround *at minimum* cover off the capital investment involved in implementing the collaborative workspace. Other significant un-quantified cost savings (e.g., on office supplies and communication spending) are reasonably considered as indicators of improved cost effectiveness.

Table 1 Duration and Elapsed Time of Selected QC Process Tasks

Tasks in QC Process	GeoPM		ETB'96	
	Duration (hour)	**Elapsed Time (hour)**	**Duration (hour)**	**Elapsed Time (hour)**
Data Submission (Packing & Shipping)	1	1	24	48
Data Receiving (Checking & Loading Files)	2	2	8	24
QC Program Invoking & Results Summary	4	4	40	120
Manual QC Inspection	5 days	5 days	5 days	5 days
Data Retuning (Packing & Shipping)	1	1	24	48
Data Resubmission (Packing & Shipping)	1	1	24	48
Final Data Delivery	1	1	24	48
Total (without resubmission)	**5.3 days**	**5.3 days**	**9 days**	**15 days**
Total (with resubmission)	**5.5 days**	**5.5 days**	**11 days**	**19 days**

Other research results indicated that, using the existing Internet infrastructure to transfer data files involved in GIS data production projects, the performance is still limited to the actual network traffic conditions and unexpected network interruptions. While transferring multiple small-size data files in one FTP session may be acceptable, transferring large-size image files in the same way is problematic. The related functions were designed in such a way that data files can be optionally transferred on an individual basis, which mostly ensures the successful transfer of both small-size data files and large-size image files. This, however, impose extra workload on handling data transfer tasks.

The research results also indicates, through the development of the collaborative workspace, difficulties in finding appropriate software components that are commercially available in the market and are not required to be used together with other unwanted systems. This compromises the component-based design principles followed in the model development in this research. As a result, the prototype development was forced to adopt a hybrid approach of integrating both software components and commercially available software systems. The integration of these components and systems is not a trivial task because of the different software interfaces and designs adopted, which required fairly amount of programming work to put them together.

The developed collaboration model facilitates the use of emerging technologies such as groupware and workflow to improve the efficiency and productivity of the collaborative GIS data production by ensuring information concurrency, accessibility and availability, and more importantly, a reengineered workflow process which allows the better control and execution of the associated production project activities and procedures. The GIS data production processes have been characterized as "data-centric" processes because the "flowing" of data files through the processes actually controls the progress. In this sense, all other project resources should be associated with data files as much as possible to ensure a consistent management manner in the collaborative workspace.

5 Concluding Remarks

In summary, this research, funded by GEOIDE project DEC#02, brought together GIS, Internet, Groupware, and Data Warehousing principles and applied them into a real-world GIS data production environment to provide solutions for better production problem solving, operational process control, project information sharing, and project management. The outcomes of this research indicate that 1) CSCW technologies such as workflow can be used to effectively facilitate collaborative GIS data production tasks if a *"sound"* model is in place and 2) the process performance are justified at least based on the analytical results from in-lab simulating testing. The systematic approach described should be valuable and useful as a framework for any other similar effort. Some issues, however, have not been well addressed given the time constraints and further investigations should be made. These are:

1. All data involved in the underlying data production project should be stored and managed in a GIS database and archived in a data warehouse.

2. The production processes controlled by the project participating companies should be integrated with the project-wide process to obtain the maximum gains of time efficiency and cost effectiveness.
3. A set of semantics for markup and annotation of shared objects in collaborative GIS should be developed to facilitating the implementation and interpretation of groupware-based GIS functions.
4. The overall performance of the collaborative workspace should be tested and analyzed in real-world production environments to obtain better understanding on improved time efficiency and cost effectiveness.
5. A collaborative GIS data production portal should be investigated by extending the research results to handle multiple GIS data production projects over the Internet.

The significance of this research may be extended, in part or full, to benefit other geomatics areas beyond distributed GIS data production. The research outcomes relate to formal modeling of processes, decision-making through enhanced communications, information sharing among widely dispersed people, and automatic process control and executions. These may imply potentials usage in (1) public GIS participation for rating public participations, voting on public opinions, sharing spatial views of different arguments, and communicating with decision-makers and other public participants; (2) collaborative spatial decision-making for distributing required information, controlling decision-making processes across wide areas, and sharing spatial decision models; and (3) using workflow technologies for automating extract-transform-load-detect-notify-refresh process of updating GIS data warehouses.

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