

**IT INTEGRATION STRINGS FOR
WATER TRANSMISSION
PROJECT PLANNING AND DESIGN**

JAMES T. O'CONNOR, P.E., PH.D.

ALEXANDER P. MORITZ

CENTER FOR CONSTRUCTION INDUSTRY STUDIES

REPORT NO. 28

THE UNIVERSITY OF TEXAS AT AUSTIN

IT Integration Strings for Water Transmission Project Planning and Design

**By
James T. O'Connor, PE, Ph.D.
Alexander P. Moritz**

**A Report to the
Center for Construction Industry Studies
The University of Texas at Austin**

**Under the Guidance of the
Fully Integrated and Automated Project Processes
Thrust Steering Team**

**Austin, Texas
August 2002**

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EXECUTIVE SUMMARY

After developing information technology (IT) automation islands for capital project delivery in the last 15 years, the construction industry is taking on the next paramount step to increase project performance: IT integration. This report presents a methodical approach at identifying high priority information technology integration strings in water transmission project planning and design. The process for identifying integration strings includes the following milestones:

- Identification of major project process and commonly used IT tools;
- Creation of data models for project phases;
- Development of metrics to identify high priority integration strings;
- Specifications for closing integration gaps;

Major findings of IT integration for water transmission project planning and design include the following:

- Limited digital data sharing between utilities and public work departments during capital improvement planning, resulting in less effective decision making by design consultants in the early stages of the project;
- No digital data exchange between CADD-based pipeline route development and structural analysis of pipeline components;
- Disconnections between pipeline route drafting/design and cost estimating tools are apparent in the missing links between CADD-based route development and manual quantity take-off;
- Request-For-Quotes (RFQ) processes, for example commonly exclude functionality pertaining to requesting, receiving, and using suppliers' data in digital format, thus disconnecting all work functions in which the information is needed;
- Disconnected owner and design consultant project controls systems exist;
- IT tool developers should provide enhanced Import/Export functionality for major IT tools such as GIS, CADD and estimating. Integration efforts with a smaller scope can be achieved in-house by using the programming capabilities available within most IT tools;
- The integration of project controls systems such as cost controls and scheduling can be achieved by developing proprietary databases with the help of program managers with in-house IT capabilities.

The study revealed that the IT tool integration gaps presented in this study partly exist due to the fact that a few large automation islands dominate. In addition, standard data exchange protocols for engineering and construction are far from being implementable, and the costs and benefits of integrated project processes are difficult to ascertain.

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TABLE OF CONTENTS

LIST OF TABLES	VI
LIST OF FIGURES	VII
CHAPTER 1 INTRODUCTION.....	1
1.1 Background and Need	1
1.2 Study Objectives.....	1
1.3 Scope and Limitations	1
1.4 Structure of Report	3
CHAPTER 2 METHODOLOGY.....	5
2.1 Methodology Flow Chart	5
2.2 Establish Research Objectives and Scope	6
2.3 Review Literature and Web Sources	6
2.4 Plan Data Collection.....	6
2.5 Conduct Interviews.....	6
2.6 Develop Work Process Maps and Data Model.....	7
2.7 Develop Integration Need Analysis Method	7
2.8 Conduct Integration Needs Analysis	8
2.9 Make Recommendations	8
CHAPTER 3 LITERATURE REVIEW.....	9
3.1 The State of the Water Infrastructure	9
3.2 Industry Trends.....	10
3.3 Information Technology in Water Infrastructure Project Delivery	10
3.4 Benefits and Barriers of Electronic Data Exchange	12
3.5 Strategies for Enhanced Integration	13
3.6 The Need for an IT Integration Gaps Analysis.....	16
CHAPTER 4 MODEL DEVELOPMENT	17
4.1 The Data Model.....	17
4.2 Data Model Analysis	35
4.3 Sample IT Integration Gap Assessment	40
CHAPTER 5 SPECIFICATIONS FOR ENHANCED INTEGRATION.....	43
5.1 High Priority Integration Strings	43
5.2 Specifications for Enhanced Integration.....	51
CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS.....	61
6.1 Conclusions	61
6.2 Recommendations	64
REFERENCES.....	65
LIST OF STUDY PARTICIPANTS	67

LIST OF TABLES

Table 4.1: IT tool inventory – 1/4	26
Table 4.2: IT tool inventory – 2/4	27
Table 4.3: IT tool inventory – 3/4	28
Table 4.4: IT tool inventory – 4/4	29
Table 4.5: Work function users	30
Table 4.6: Schedule of initial data elements	31
Table 4.7: Schedule of evolving data elements.....	32
Table 4.8: Schedule of evolving data elements – continued	33
Table 4.9: Schedule of deliverables	34
Table 4.10: Influence diagram and index parameter relationships	35
Table 4.11: Data model analysis table	37
Table 4.12: Integration Need Index (INI) parameter scoring	39
Table 4.13: Integration Capability Index (ICI) scoring	40
Table 4.14: Example data model analysis table for WP1 and WP2.....	42
Table 5.1: Selected high priority integration strings.....	44
Table 5.2: Selected high priority integration strings – continued	45
Table 6.1: High priority integration strings	62
Table 6.2: High priority integration strings – continued.....	63

LIST OF FIGURES

Figure 1.1: Scope of study within water infrastructure.....	2
Figure 1.2: Scope of study within project delivery life-cycle.....	2
Figure 2.1: Methodology flow chart	5
Figure 2.2: Integration gaps analysis components	8
Figure 3.1: Common architectures for enhanced IT tools integration	15
Figure 4.1: Data model legend.....	18
Figure 4.2: Data model level 1	19
Figure 4.3: Data model level 2-1 – planning and feasibility	20
Figure 4.4: Data model level 2-2 – site investigation & preliminary design	21
Figure 4.5: Data model level 2-3 – final design.....	22
Figure 4.6: Data model level 2-4 – owner project administration – 1/2	23
Figure 4.7: Data model level 2-4 – owner project administration – 2/2	24
Figure 4.8: Data model level 2-5 – DC project management	25
Figure 4.9: Influence diagram for prioritizing high integration strings	36
Figure 5.1: WP integration need vs. capability diagram.....	43
Figure 5.2: Selected high priority integration strings in planning & feasibility	46
Figure 5.3: Selected high priority integration strings in site investigation & pre-design	47
Figure 5.4: Selected high priority integration strings in final design.....	48
Figure 5.5: Selected high priority integration strings in owner project administration	49
Figure 5.6: Selected high priority integration strings in DC project management	50
Figure 5.7: Legend for integration strategies	51
Figure 5.8: Specifications for WP4.....	52
Figure 5.9: Specifications for WP6.....	52
Figure 5.10: Specifications for WP8.....	53
Figure 5.11: Specifications for WP15.....	53
Figure 5.12: Specifications for WP16.....	54
Figure 5.13: Specifications for WP42.....	54
Figure 5.14: Specifications for WP45.....	55
Figure 5.15: Specifications for WP46.....	55
Figure 5.16: Specifications for WP47.....	56
Figure 5.17: Specifications for WP48.....	56
Figure 5.18: Specifications for WP49.....	57
Figure 5.19: Specifications for WP50.....	57
Figure 5.20: Specifications for WP55.....	58
Figure 5.21: Specifications for WP59.....	58
Figure 5.22: Specifications for various WP	59
Figure 5.23: Specifications for various WP	59

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CHAPTER 1 INTRODUCTION

1.1 Background and Need

After developing information technology (IT) automation “islands” for capital project delivery in the last 15 years, the construction industry is taking on the next paramount step to increase project performance: IT integration. Infrastructure projects have been found to have a high degree of automation, apparent in systems such as Geographic Information Systems (GIS), commodity modeling tools, and Computer Aided Design and Drafting (CADD). However, IT integration efforts in this industry sector have been focusing on connecting pairs of tools rather than integrating the entire project delivery process.

Nevertheless, there may be further areas where IT integration priorities are high and where the closing of these gaps would lead to improved project performance. However, identifying these gaps can be difficult, as a thorough methodology is lacking. This research is an attempt at systematically analyzing the gaps in the integration of IT tools and identifying high priority integration needs in water infrastructure project delivery.

1.2 Study Objectives

The following objectives were pursued when conducting this study:

- Understand and abstract project processes and IT tools at a component level;
- Create an IT tool inventory as part of a tool mapping exercise to identify integration capabilities or opportunities;
- Provide a snap shot of the current integration level of infrastructure project processes and IT tools;
- Develop a new systematic approach for identifying high priority needs for system integration.

1.3 Scope and Limitations

The general scope of this study was arbitrarily limited to planning, engineering and project management of water infrastructure capital projects. Two other similar studies are underway for power infrastructure and telecommunication capital projects. Within the water infrastructure category, projects such as plants, station, and other building structures were excluded to allow for more focus. Pipeline rehabilitation projects were excluded from the study to further narrow the scope. Figure 1.1 shows the scope limitations within the water infrastructure projects category.

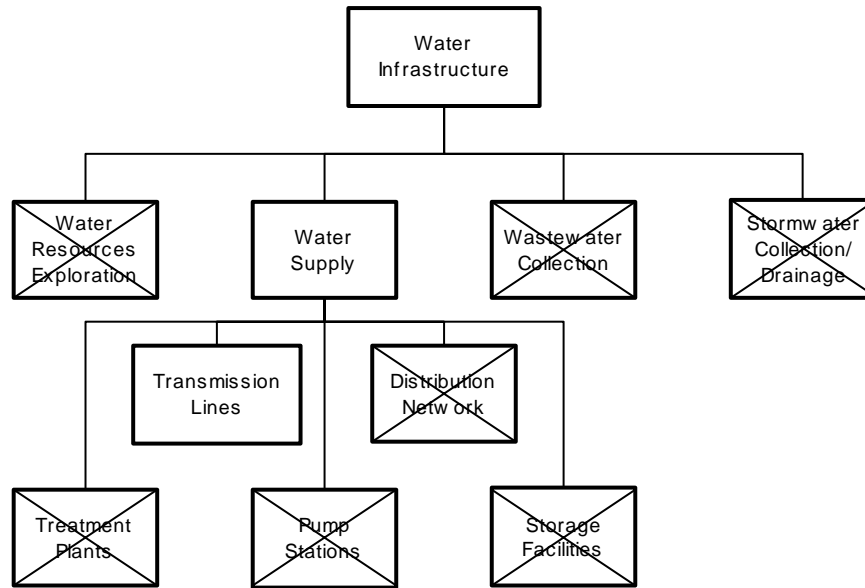


Figure 1.1: Scope of study within water infrastructure

Study scope was further limited to planning, engineering, and associated project management activities. Procurement activities were excluded as most water utilities do not pre-purchase long-lead equipment for these types of projects. Figure 1.2 illustrates these further scope limitations.

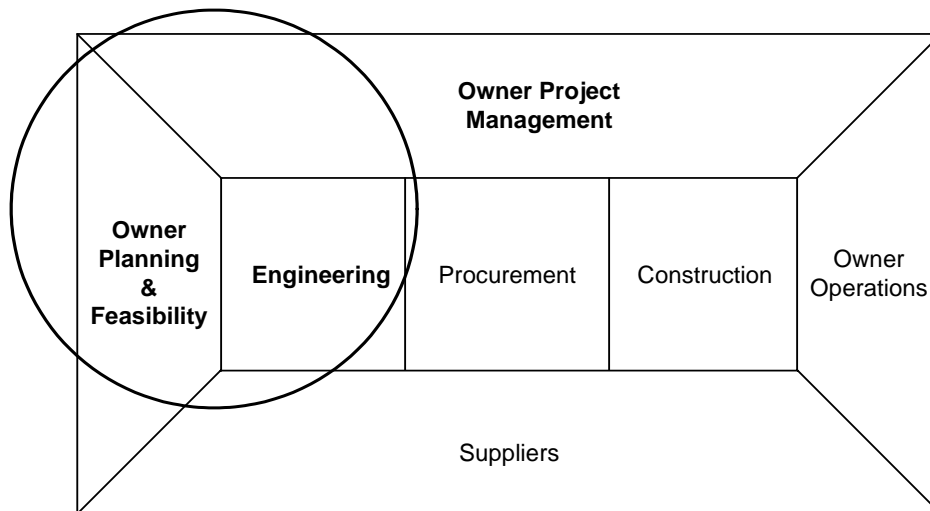


Figure 1.2: Scope of study within project delivery life-cycle

The number of participants was limited to one (1) large water utility without in-house design capabilities and three (3) design firms. Only major industry players participated in this study,

since such organizations/firms are more likely to apply state-of-the-art information technology on their capital projects.

1.4 Structure of Report

This report contains a total of six chapters. Chapter 2 briefly describes the methodology followed throughout the study. It includes a general flow chart as well as descriptions of study activities. In Chapter 3 a brief literature review addresses current water infrastructure trends and IT trends specific to this industry. Chapter 4 presents the data analysis model that was developed in this study. The underlying metrics are explained and an example integration gaps analysis is presented to demonstrate its application. Chapter 5 presents the findings of the analysis, including high priority integration strings and general specifications for their achievement. Chapter 6 recaps study conclusions and offers recommendations for future related studies.

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CHAPTER 2 METHODOLOGY

2.1 Methodology Flow Chart

Figure 2.1 illustrates the methodology used for the study presented in this document.

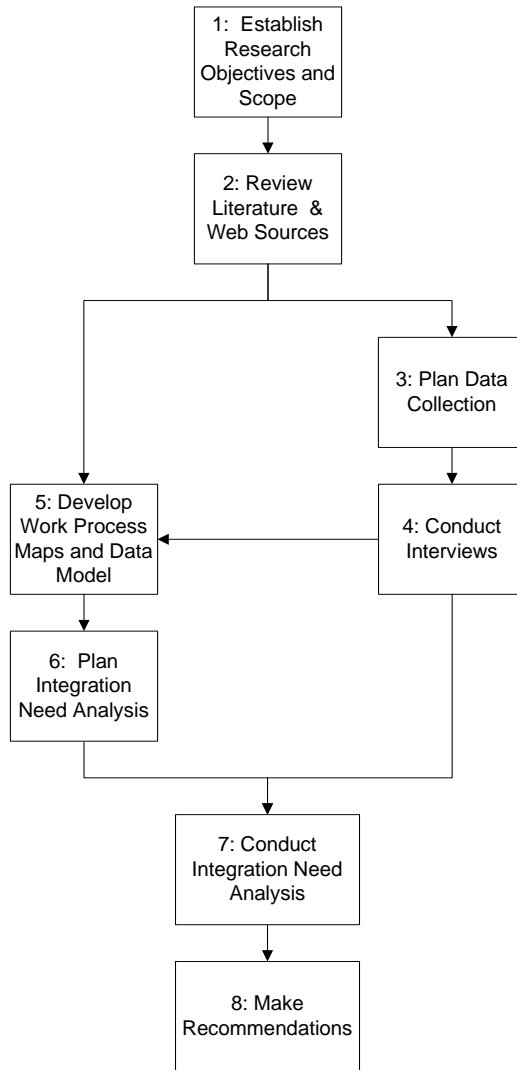


Figure 2.1: Methodology flow chart

2.2 Establish Research Objectives and Scope

Study objectives were established in the context of previous FIAPP studies. The scope of the study was further narrowed based upon industry reviews and personal interests of the research team.

2.3 Review Literature and Web Sources

A literature review was conducted in order to identify industry-specific work processes and related IT issues. The types of resources reviewed included the following:

- Standard literature on water-resources systems engineering and IT;
- Previous CII and CCIS research;
- Industry related periodicals;
- Web pages of major IT tool developers identified from periodicals.

2.4 Plan Data Collection

A data set was targeted for collection in order to accomplish the stated objectives. The data collection set consists of:

- Generic work process maps;
- IT tool overlays;
- IT tool system data sheets.

Most of the information was collected via personal on-site company interviews with senior project managers and engineers.

2.5 Conduct Interviews

Prospective companies in the water industry were solicited for participation in the study. The work processes of the respondent companies were identified using the generic work process map as a starting framework. An inventory of IT tools was developed with the use of IT tool overlays.

2.6 Develop Work Process Maps and Data Model

Generic process maps were modified to reflect the work processes of each respondent company. A data model was created using the information gathered from company interviews and a second in-depth literature and web-sources review. The data model is an abstract form of the generic process maps. It illustrates the flow of data between certain functions performed during the planning and design of water pipeline projects.

2.7 Develop Integration Need Analysis Method

An influence diagram was created to identify factors that offer insight into high priority IT system integration strings. The Integration Need Index (INI) and Integration Capability Index (ICI) were developed to enable an assessment of work processes (WP) and the flow of data. A parameter scoring system was developed to enable calculation of the INI and ICI on the data model for each WP. A data model analysis table was created to display the parameter scores, parameter weights, and results from the INI and ICI calculations for each WP. A work process integration priority diagram was created to plot WP's according to their INI and ICI. Figure 2.2 illustrates the relationship between the different components of the analysis method.

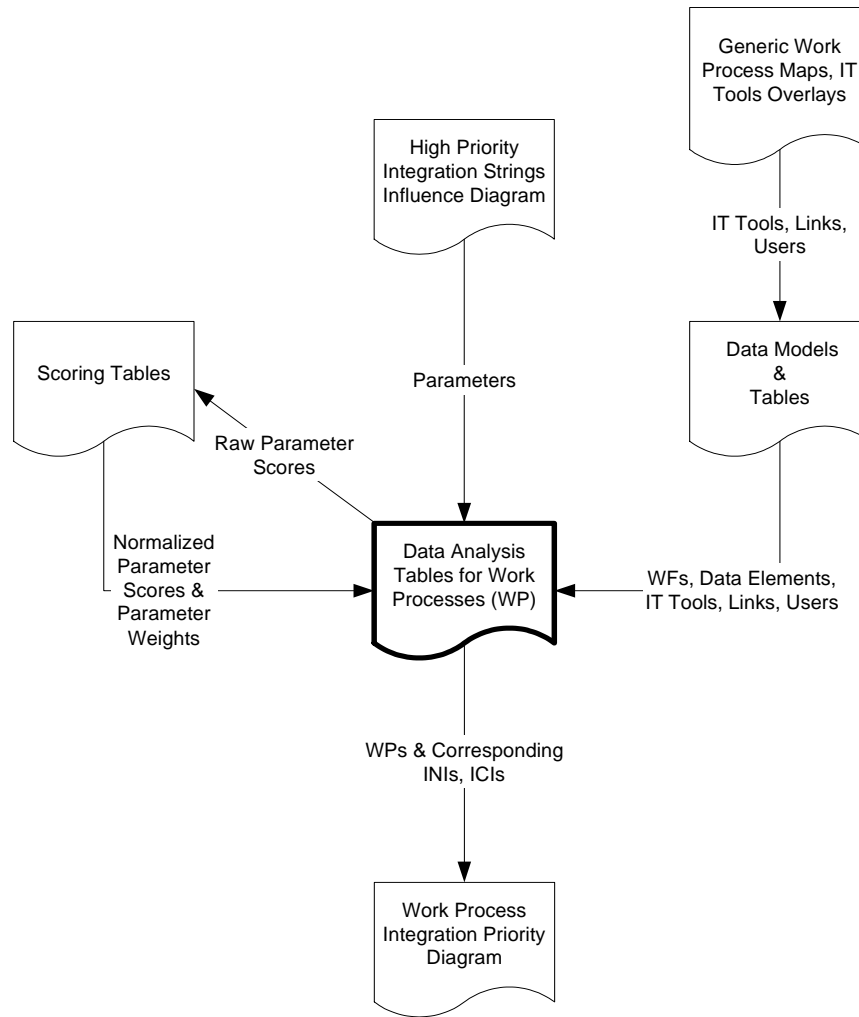


Figure 2.2: Integration gaps analysis components

2.8 Conduct Integration Needs Analysis

The INI and ICI for each WP on the data model were calculated using the Data Model Analysis Table. Each WP was plotted on the Integration Priority Diagram. WP's with a high INI and low ICI were identified as high priority integration strings and were targeted for further analysis.

2.9 Make Recommendations

Specifications for the enhanced integration of high priority integration strings were detailed in integration specification figures. Recommendations for future work were identified.

CHAPTER 3 LITERATURE REVIEW

3.1 The State of the Water Infrastructure

The US water infrastructure is a large and complex system of interrelated subsystems. Chin (2000) organizes water-resource systems into:

- Water-control systems consisting of flood-control structures such as drainage systems, storage reservoirs and storm-sewer systems;
- Water-use systems consisting of water-treatment, water-distribution, wastewater-collection, and wastewater-treatment.

Water-use systems or the water supply infrastructure can be further broken down into water resources (surface water or groundwater), treatment plants, pumping stations and storage reservoirs, transmission pipelines, and the distribution system (Mays, 2000). In wastewater collection and treatment as well as combined sewer systems, similar infrastructure subcomponents can be identified that correspond to the ones listed above: rivers, wastewater treatment plants, lift-stations and detention facilities, and outfalls or pressurized interceptors and the sewer system (ASCE, 1986). Also competing for limited space in cities is the flood control system consisting of engineered drainage channels, natural creeks, underground pipelines, detention ponds, flood plains, lift stations and outfalls.

Due to the magnitude of the water infrastructure, it is obvious that in order to operate, maintain and upgrade infrastructure assets, large capital investments have to be made on an annual basis. The Water Infrastructure Network (WIN), a coalition of public and private water groups, estimates that US water utilities will have to invest nearly \$1 trillion in treatment plants, distribution and wastewater collection systems over the next 20 years to replace and upgrade the aging water infrastructure (WIN, 2000). Adding to concerns over an aging water infrastructure, more stringent environmental regulations imposed by the US Environmental Protection Agency (USEPA) and other regulators will further increase the pressure on water utilities to improve their infrastructure. Furthermore, a 20% growth in US population by 2020 could mean that providing residential water supply services will continue to be a growing business. This may be especially valid for the southern and western regions of the US where the population growth has been concentrated over the last 30 years (Dixon, 2001).

The awareness of this population growth paired with the limited availability of water-resources is already being reflected in some water utilities' current projects throughout the US. Utilities in the Puget Sound region of Washington State, for example, are faced with increasing water demands and stricter water quality standards. The results are so-called "intertie" water supply projects, in which utilities are forced to connect their remote supply systems through large diameter transmission lines (Palmer, 2001). In other regions of the US, projects with similar objectives and scope can be found. In one of the US fastest growing cities, San Antonio, Texas, the San Antonio Water System (SAWS), for instance, is currently upgrading its water supply system to integrate remote water sources over the next 50 years (SAWS, 2001).

Flood control projects are also on the rise. After hurricane Allison left thousands of people homeless in the City of Houston, large upgrading projects were initiated to solve the city's problems. Other coastal cities such as New Orleans are also preparing their drainage systems for the threats of flooding by expanding canals, underground culverts and upgrading pump stations and detention structures (Parsons, 2000).

3.2 Industry Trends

The most recent trends in water utility management are deregulation, privatization and outsourcing. Beaudet (Beaudet, 2000) concludes "the most significant and possibly the most controversial catalyst for change is privatization". Along with privatization comes the outsourcing of noncore utility functions such as meter reading, laboratory work, billing, and landscaping. Outsourcing and subsequent industry fragmentation is particularly on the rise, because "many public utilities have launched efforts to increase their competitiveness" (Beaudet, 2000). One proof of this outsourcing trend is the hiring of program management consultants for multi-year municipal capital improvement works in large cities such as Houston, Boston, Los Angeles, New Orleans and Atlanta (Gribbins, 2000).

Fragmentation is also the result of the traditional splitting of engineering tasks between owners, design consultants and contractors in general. While build-operate-transfer (BOT) contracts have become a common project delivery approach for treatment plants under tight schedule, the design-bid-build approach remains the standard project delivery method for pipeline projects. However, the design-build approach may be more frequently applied in the future due to a growing demand for accelerated project schedules caused by imposed environmental regulations. The City of San Diego's water department, for example, just recently awarded one of the nation's first design-build public piping infrastructure contracts (Crockett, 2001). This project delivery approach inevitably leads to an increasing number of responsibilities and interrelated work functions that need to be shared between the utility, designer consultants, and the contractor during early project planning stages.

One result of outsourcing and fragmentation within the water industry is an increased competition between design firms in the public and private utility market. Tulacz (ENR Magazine April 10, 2000) concludes that "the industry prosperity has led to an increase in consolidation among companies."

3.3 Information Technology in Water Infrastructure Project Delivery

Water utilities have invested tremendous amounts into information technology (IT) in the recent past. GIS-based asset management has become the state-of-the-art for most water utilities and public works departments. The American Water Works Association (AWWA) stated that ninety (90) percent of all water utilities in the United States would be using GIS technology by the end of last year. According to the industry leader in GIS software, ESRI, "the use of GIS technology is rapidly expanding in the water/wastewater industry, moving from project-specific implementation to full enterprise-wide installations. [...] Another use of GIS that is helping the water/wastewater industry function more efficiently is its linking with hydraulic models.

Information can be passed between the GIS and the model, which simplifies the tremendous effort that it takes to create and refine the model. [...] GIS is being used more and more for network expansion in determining the location of existing lines and planning where new ones should be added. [...] It is also being used for inventory management and project tracking” (ESRI ArcNews, Spring 2001).

Apart from GIS, infrastructure capital asset management, and integrated hydraulic modeling, electronic procurement of construction services is also being targeted in the water utility management sector on a broader level. For example, AWWA just recently partnered with a private company to develop and launch EfficientUtilities, a web-based procurement solution for the water utility industry. AWWA claims that “the site optimizes procurement and related business functions for buyers and sellers of equipment, products and services within the utility and related construction industries by enhancing current, proven business practices in a more efficient and automated internet environment.” AWWA further promotes the site, stating “input from various segments within the water and wastewater community is an integral part of the site offering” (EfficientUtilities, 2001).

On a construction industry-wide level numerous standards initiatives have been started in order to further promote IT tool integration. The International Alliance for Interoperability (IAI) is currently pursuing the development of a universal integration standard, called aecXML. This standard “is intended to be used as an XML namespace and to facilitate information exchange of AEC data on the Internet (IAI aecXML, 2001). According to Hubers (2001), this integration standard initiative has the highest potential for development and deployment in the construction industry. Focusing on a subgroup of the industry, Autodesk, a major CADD software developer for the construction industry, started its own data standard initiative for civil engineering projects called LandXML in 1999. “LandXML specifies a design data structure that:

- Transfers civil engineering/survey design data between producers and consumers.
- Provide a data format suitable for long-term data archival.
- Provide a standard format for official electronic design submission.
- LandXML data may also be used as:
 - Source data for quantity take-off, cost estimation.
 - Source data for custom calculations and reports.
 - Accessible design data from remote/field devices.
 - Data extraction and submittal format for GIS databases.
 - Engineering design data transport layer for collaborative applications” (LandXML.org, 2001).

The latest development for XML-based interaction through the Internet is the geographic markup language (GML). GML is based on the OpenGIS encoding standard for geographic information. The OpenGIS data standard is currently developed by the OpenGIS Consortium (OGC) and intended to enable “full integration of geospatial data and geoprocessing resources into mainstream computing and the widespread use of interoperable geoprocessing software and geodata products throughout the information infrastructure” (OpenGIS Consortium, 2001).

3.4 Benefits and Barriers of Electronic Data Exchange

The benefits of electronic data exchange and barriers to IT integration have been addressed in previous research. The major benefits of computerization and data integration that have been identified are:

- “Production of consistent drawings;
- Enabling concurrent engineering and design leading to shorter time spans for design;
- Avoiding repeated data input and related mistakes;
- Improved data integrity and quality;
- Reducing rework and design control checks;
- Increasing productivity through quicker, error-free information exchange and communication;
- Allowing for easier design modifications;
- Elimination of redundant data collection and entry;
- Easy reuse of data on current and future projects;
- Increasing interdisciplinary awareness and cooperation” (Hubers, 2001).

Although these benefits seem straight-forward, the construction industry has been very slow in developing and adopting IT integration. Hubers identifies barriers specifically to the development of universal data exchange standards in his recent in-depth study as follows:

- “Uncertain benefits;
- High cost of participation in development;
- Difficulty in reaching consensus;
- Vendor hesitation in implementation;
- Reluctance to change from existing company standards;
- High cost of implementation” (Hubers 2001).

Part of the dilemma described above could be the fact that most industry publications focus on IT integration deployment and implementation rather than addressing costs and benefits from process changes in detail. A document published by the Construction Industry Institute (CII) on process-based IT integration in EPC projects arrives at the following conclusion:

“Unfortunately, too much effort has been placed on information technologies or upon certain activities assumed to be critical to schedule and cost objectives. This may be due to the fact that, to date, no methodology has been developed to examine the contribution of information management in reducing overall project schedule and cost. The inability of the industry to quantify the process improvements resulting from information management strategies is a key barrier to their full implementation” (Determining the Impact of Process Change on the EPC Process, 1997).

3.5 Strategies for Enhanced Integration

In order to fully integrate IT tools throughout the project life-cycle, strategies numerous integration techniques can be applied. This chapter briefly highlights a few major strategies for closing integration gaps. The discussion of the details of all these strategies is beyond the scope of this document.

Linthicum (Linthicum, 2000) identifies four technical approaches to enterprise application integration (EAI):

- “Data level (data);
- Application interface level (packaged application);
- Method level (business process);
- User interface level (the legacy).”

Linthicum (Linthicum, 2000) describes data-level EAI as “the process – and the techniques and technology – of moving data between data stores by extracting information from one database, perhaps processing that information as needed, and updating it in another database.”

Application interface-level EAI aims at utilizing interfaces provided by custom or packaged applications. System developers use the packages’ interfaces to access both business processes and simple information.

Method-level EAI is a relatively complex form of integration. This approach utilizes the business logic within the enterprise. The mechanisms to share methods among applications include distributed objects, application servers, TP (transaction processing) monitors, and frameworks. The simplest form of this integration approach is the creation of a new application using a combination of two or more applications.

Using interface-level EAI approach, architects and developers are able to bundle applications by using their graphical user interfaces (GUI) as a common point of integration. This is also known as ‘screen scraping’ (Linthicum, 2000).

In this document, three basic strategies for capital project IT integration have been synthesized from multiple sources and are applied in Chapter 5 to recommend strategies for closing integration gaps. These basic strategies are:

- Application-to-application (A2A) integration using data level and user interface level integration strategies;
- Proprietary database integration using the data level and packaged application integration approach;
- Standard data exchange language integration using the pure data level integration approach.

Application-to-Application (A2A) Integration

A2A Integration is probably the oldest form of enabling data exchange between disconnected IT tools. This technique uses integration schemes both on a data level as well as through the graphical user interface (GUI) of an IT tool. On a data level, information is stored in one tool’s

proprietary data structure and converted to a different data scheme that can be read by another proprietary tool. GUI data exchange is achieved by converting an object on the screen of one application into either a graphical representation or a simple code that can be interpreted by another tool. The data exchange in A2A integration is limited to a pair of IT tools used for performing different work functions. Therefore, numerous data exchange methods (links) between tools may exist along the entire work process. This ad-hoc approach may be most suitable for in-house application, as the main purpose is to connect distributed users within the organization. It should be the preferred method for projects with a relatively small scope and small quantities of data exchanged. Its implementation cost is comparatively low, since the underlying integration concepts do not require the software code to be changed (compare Linthicum, 2000).

Examples of A2A integration include Export/Import functionality between IT tools, Microsoft's Object Linking and Embedding (OLE) framework and simple programming routines to extract data from one tool to be used in others.

Propriety Database Integration

In this integration approach, a dominant IT tool is used to link other work functions directly to a single database. The dominant IT tool is usually the tool that is used to store the most vital information within an organization or during a capital facility project. The database uses a proprietary exchange language (link) in order to exchange data elements with these work functions. Although similar to the A2A integration approach, it differs in the fact that a relational database is used and only a single link/code is available to connect tools. Again, this approach may be most suitable for in-house application, but is usually applied on relatively complex projects where large volumes of data are exchanged and concurrent engineering is the key to a project's success. Implementation costs are substantially higher than with the A2A approach, as a single data scheme must be agreed on and implemented for all tools to be connected.

Applied proprietary database integration examples include Enterprise Resource Planning (ERP) software such as SAP, PeopleSoft, Baan and J.D. Edwards. For capital facility engineering, CADD developers such as Autodesk, Bentley and their partner developers have used the same approach to add new functionality to the basic CADD engines Microstation and AutoCAD. This is apparent through available add-on packages ranging from surveying, land development and commodity modeling to GIS and infrastructure management systems (compare Autodesk, 2001, Bentley, 2001). Links to the perimeter of the proprietary data structures are usually provided in the form of programming languages such as C++, Java or other proprietary schemes.

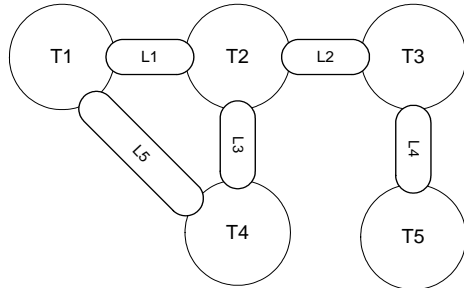
Standard Data Exchange Language Integration

A standard data exchange language is a universal code that can be instantly interpreted and used by any IT tool that complies with this code. A carrier for data exchange must be established to enable the transmission of data from one organization and its IT tools to others. The carrier - called the Buss - can be created using numerous middleware configurations. However, the backbone of the Buss is the Internet with all middleware solutions tied into it. The costs and potential barriers associated with widespread implementation in the industry were discussed in the preceding section.

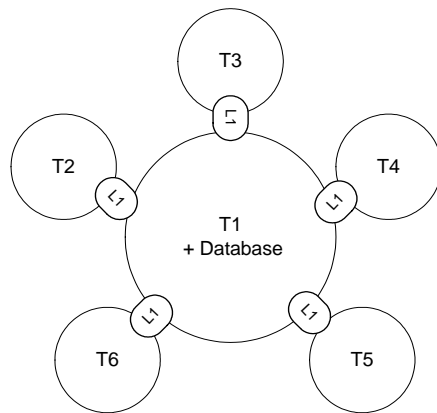
Most recent industry-wide integration efforts on developing standard exchange languages include the aecXML and LandXML initiative as well as the OpenGIS/GML approach briefly discussed in the preceding section.

Figure 3.1 summarizes these three basic integration strategies for enhanced integration.

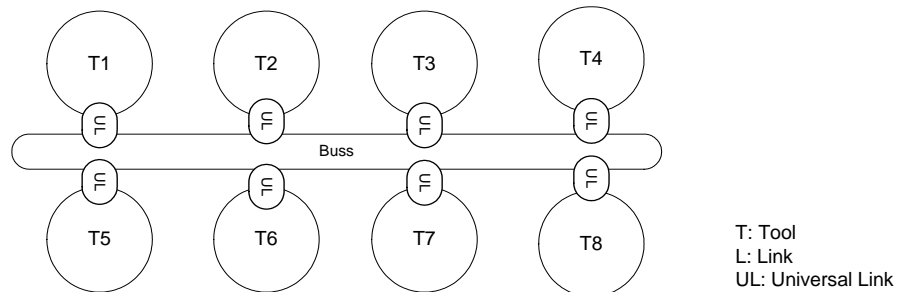
1: Application-to-Application Integration



2: Proprietary Database Integration



3: Standard Data Exchange Language Integration



T: Tool
L: Link
UL: Universal Link

Figure 3.1: Common architectures for enhanced IT tools integration

3.6 The Need for an IT Integration Gaps Analysis

The increased need for capital investments, continued industry fragmentation and high levels of competition amongst design firms will further drive interest in streamlining project delivery, cutting waste, and further automating and integrating IT. However the industry's focus seems to be largely on adding "islands" of automation, thus leaving users and organizations largely disconnected.

These "islands" of automation are based on proprietary data schemes and software developers have done only little in the past to promote data exchange between their IT tools. Although numerous data standards development initiatives are underway, they are not likely to affect the industry anytime soon. Hence, users of these IT tools are usually left on their own to connect their islands of automation within their organizations and between all project participants.

However, identifying the highest integration needs can often be difficult. In order to fill the gap of a structured analysis of IT integration gaps, a method for evaluating integration needs was developed and is presented in this document.

CHAPTER 4 MODEL DEVELOPMENT

4.1 The Data Model

A data model was created to chart the flow of data between work functions, users, and IT tools. The data model legend in Figure 4.1 defines the elements used to construct the data model. The data model consists of links, work functions (WF), work processes (WP), data element (DE) codes, IT tool user codes, and IT tool codes. The model itself (Figures 4.2 through 4.8) was created using information from the data collection phase and the literature review and consists of essential work functions from the work flow maps.

The data model is comprised of two levels of detail. Figure 4.2 provides a general overview of data flow between major work functions on Level 1. Level 2 of the data model was created to perform the detailed analysis and is broken into three project phases. These phases are:

- Level 2-1 Planning and Feasibility (Figure 4.3),
- Level 2-2 Site Investigation & Preliminary Design (Figure 4.4),
- Level 2-3 Detailed Design & Construction Documents (Figure 4.5),
- Level 2-4 Owner Project Administration (Figure 4.6 and 4.7),
- Level 2-5 Design Consultant Project Management (Figure 4.8).

IT tool codes, work function user codes, and data element codes indicated on the data models are explained in a set of tables following the data models. IT tools (Table 4.1 through Table 4.4) were inventoried from interviews with study participants, as were IT tool users (Table 4.5), and data elements (Table 4.6 through Table 4.9). The format of the data elements was derived from existing integration identified with the study participants. The information in these tables is useful in interpreting the data model and conducting the integration gaps analysis.

Figure 4.1: Data model legend

Figure 4.2: Data model level 1

Figure 4.3: Data model level 2-1 – planning and feasibility

Figure 4.4: Data model level 2-2 – site investigation & preliminary design

Figure 4.5: Data model level 2-3 – final design

Figure 4.6: Data model level 2-4 – owner project administration – 1/2

Figure 4.7: Data model level 2-4 – owner project administration – 2/2

Figure 4.8: Data model level 2-5 – DC project management

Table 4.1: IT tool inventory – 1/4

Table 4.2: IT tool inventory – 2/4

Table 4.3: IT tool inventory – 3/4

Table 4.4: IT tool inventory – 4/4

Table 4.5: Work function users

Primary Users	
OW	Owner
DC	Design Consultant, Prime
SP	Supplier
Sub	Subcontractor
Secondary Users	
EN	Engineer
ES	Estimator
CT	CADD Technician
PM	Project Manager

Table 4.6: Schedule of initial data elements

DE No.	Initial Data Elements	Category	DE Format
IE1	Infrastructure Components Inventory	Infrastructure & Environment	Non-Digital
IE2	Other Utilities Inventory & ROW	↓	Non-Digital
IE3	Hydrology, Geology	↓	Non-Digital
IE4	Climate/Weather	↓	Non-Digital
IE5	Available Topography Data	↓	Digital
IE6	Existing ROW /Real Estate Information	↓	Non-Digital
OM1	System Inspections/Integrity Rating	Operations & Maintenance	Non-Digital
OM2	Maintenance Work	↓	Non-Digital
OM3	Water Quality	↓	Non-Digital
OM4	Department CIP Requests	↓	Non-Digital
OM5	Operations/Controls Data	↓	Non-Digital
GE1	Population Growth	Growth & Economics	Non-Digital
GE2	Commodity Prices/Rates	↓	Non-Digital
GE3	Water Supply Demand	↓	Non-Digital
GE4	Existing Hydraulic Water Models	↓	Mix
GE5	Water Resources Availability	↓	Non-Digital
GE6	Funding Availability	↓	Non-Digital
RC1	Environmental Regulations	Regulatory Compliance	Non-Digital
RC2	Design Standards	↓	Non-Digital
RC3	Safety Standards	↓	Non-Digital
RC4	Building Codes	↓	Non-Digital
TO1	Material Improvements	Technology Opportunities	Non-Digital
TO2	Equipment Improvements	↓	Non-Digital
TO3	Construction Technology Improvements	↓	Non-Digital
PK1	Completed Projects Summary	Projects Knowledge Base	Non-Digital
PK2	As-Build Documents & Drawings	↓	Non-Digital
PK3	Historic Project Cost Databases	↓	Non-Digital
PK4	New CIP Project Information	↓	Digital

Table 4.7: Schedule of evolving data elements

DE No.	Evolving Data Elements	Phase	DE Format
1	Alternative Pipelines Routes Locations	DM 2-1	Mix
2	Operations Requirements	↓	Non-Digital
3	Pipeline Sections Lengths		Non-Digital
4	Proposed Construction Methods		Non-Digital
5	Controls Equipment		Non-Digital
6	Selected Pipeline Route		Non-Digital
7	Proposed Timeline		Non-Digital
8	Project Description		Non-Digital
9	Project Cost Estimate		Non-Digital
10	Areal Survey Photos		DM 2-2
11	Environmental Protection Zones	↓	Non-Digital
12	Environmental Restrictions		Non-Digital
13	Social/Community Restrictions		Non-Digital
14	ROW Ownership		Non-Digital
15	Real Estate Ownership		Non-Digital
16	Real Estate Restrictions		Non-Digital
17	Real Estate Acquisition Costs		Non-Digital
18	ROW Acquisition Costs		Non-Digital
19	Route Gradients		Non-Digital
20	Proposed Pipe Materials		Non-Digital
21	Proposed Pipeline Length/Sections		Non-Digital
22	Required Pipeline Capacity (Flow, Pressure, Size)		Non-Digital
23	Equipment Capacity Requirements		Non-Digital
24	Equipment Power Requirements		Non-Digital
25	Equipment Size/Dimensions		Non-Digital
26	Equipment Details		Non-Digital
27	Equipment Type		Non-Digital
28	Equipment Locations/Coordinates		Digital
29	Route Coordinates		Non-Digital
30	Route Surface Model		Digital
31	Physical Above-Ground Obstacles		Digital
32	Identified Underground Utilities		Non-Digital
33	Soil Layers		Non-Digital
34	Soil Properties		Non-Digital

Table 4.8: Schedule of evolving data elements – continued

DE No.	Evolving Data Elements	Phase	DE Format
35	Groundwater Levels	DM 2-2	Non-Digital
36	Identified Project Risks		Non-Digital
37	Proposed Construction Methods		Non-Digital
38	Preliminary Material Costs		Non-Digital
39	Equipment Cost Quotes		Non-Digital
40	Preliminary Construction Costs		Non-Digital
41	Pipe Wall Thickness	DM 2-3	Non-Digital
42	Pipe Material Requirements		Non-Digital
43	Pipe Length/Sections		Non-Digital
44	Pipe Cost Quotes		Non-Digital
45	Pipe Type		Non-Digital
46	System Dynamic Loads		Non-Digital
47	Support Structure Requirements		Non-Digital
48	Support Structure Dimensions		Non-Digital
49	Support Structure Details		Non-Digital
50	Support Structure Installation Locations		Digital
51	CP System Requirements		Non-Digital
52	CP System Cost Quotes		Non-Digital
53	CP System Details		Non-Digital
54	CP System Type		Non-Digital
55	CP System Installation Locations		Digital
56	Electrical System Requirements		Non-Digital
57	Electrical System Costs Quotes		Non-Digital
58	Electrical Details		Non-Digital
59	Electrical System Type		Non-Digital
60	Electrical System Installation Locations		Digital
61	Bedding/Backfill Requirements		Non-Digital
62	Construction Site Locations		Non-Digital
63	Pipeline Depth		Non-Digital
64	Work Breakdown Structure		Mix
65	Cost Breakdown Structure		Non-Digital
66	Work Description		Non-Digital
67	Timeline		Non-Digital
68	Phase Milestone Dates		Non-Digital
69	Design Changes		Non-Digital
70	Cost Updates		Non-Digital
71	Progress Updates		Non-Digital

Table 4.9: Schedule of deliverables

DE No.	Deliverables	Phase	Deliverable Format
A	Water System Master Plan	DM 2-4/2-5	Non-Digital
B	Alternative Route Plans		Non-Digital
C	Alternative Order of Magnitude Cost Estimate		Non-Digital
D	Environmental Impact Statement		Non-Digital
E	Preliminary Route Plan		Non-Digital
F	Controls Equipment Schedule		Non-Digital
G	Preliminary Engineering Cost Estimate		Non-Digital
H	Technical Feasibility Analysis		Non-Digital
J	Geotechnical Baseline Report		Non-Digital
K	Plans & Profiles Drawings		Non-Digital
L	Specifications		Non-Digital
M	Details Drawings		Non-Digital
N	Engineering Cost Estimate	↓	Non-Digital
O	Front-End Documents		Non-Digital
P	Owner-DC Contract	DM 2-5	Non-Digital
Q	Owner Milestone Schedule & Reports		Non-Digital
R	Owner Project Cost Budget		Non-Digital
S	DC Detailed Schedule & Reports		Non-Digital
T	DC Project Cost Budget		Non-Digital
U	Owner Cost Reports		Non-Digital
V	DC Cost Reports		Non-Digital
X	ROW Acquisition Package		Non-Digital
Y	Permit Acquisition Package	↓	Non-Digital

4.2 Data Model Analysis

The influence diagram shown in Figure 4.9 was created to derive and better understand the parameters used to calculate the Integration Need Index (INI) and Integration Capability Index (ICI) of each Work Process (WP). Table 4.10 characterizes the relationship between influence diagram nodes and parameters used to calculate the indices by describing the relevance of each factor in contributing to integration needs and capabilities.

Table 4.10: Influence diagram and index parameter relationships

Influence Diagram Node No.	Corresponding Analysis Table Parameter	Relevance of Influence Diagram Node to Integration Need/Integration Capability
1	No. of Exchanged DE in WP	High data quantity exchange between tools increases the probability of transmission errors.
2	% of Non-Digital DE Exchanged in WP	Exchange of non-digital data is indicative of disconnected tools.
3	No. of Different Users in WP	Lack of integration between organizations hinders communication and increases the probability of transmission errors.
4	No. of Different Users in WP	Lack of integration between users hinders communication and increases the probability of transmission errors.
5	No. of Different Tools used in WP	Large number of disconnected tools increases the probability of transmission errors.
6	Contributes to the ICI	Integration of tools is not possible without first automating a given process.
7	Contributes to the ICI	Increased integration between existing tools correlates to a high integration capability index.

In order to prioritize integration strings, an Integration Need Index (INI) and an Integration Capability Index (ICI) were created to enable a relative assessment of each WP in the data model. An analysis table (Table 4.11) was created to analyze the data model and identify high-priority integration strings.

Figure 4.9: Influence diagram for prioritizing high integration strings

Table 4.11: Data model analysis table

Integration Need Index Calculation

Four parameters were identified as major contributors to increasing the integration need of disconnected work functions. The parameters are:

- Parameter 1 (P1): No. of Exchanged DE in WP;
- Parameter 2 (P2): % of Non-Digital DE Exchanged in WP;
- Parameter 3 (P3): No. of Different Users in WP;
- Parameter 4 (P4): No. of Different Tools used in WP.

The first step of the INI calculation is to assign raw or absolute scores to each parameter listed above. These raw scores are directly derived from the parameter definitions. For example, the number of different tools is directly read off the data model.

Each parameter's raw score is then normalized using the scale shown in Table 4.12. Each parameter had to be weighted using the multiple of ones method to account for the relative impact of each parameter on the INI. Based on the authors' judgment, the parameters are listed below in order of descending importance:

- Parameter 1;
- Parameter 3;
- Parameter 4;
- Parameter 2.

Using the multiple of ones method, Parameter 2 - % of Non-Digital DE Exchanged in WP - is given a score of 1, Parameter 4 - No. of Different Tools used in WP - is given a score of 1.5, Parameter 3 - No. of Different Users in WP - is given a score of 2.0, and Parameter 1 - No. of Exchanged DE in WP - is given a score of 2.5. As a result, the weight of each parameter is calculated as follows:

$$\begin{aligned}\text{Weight for P1 (Wt P1)} &= 2.5/(1 + 1.5 + 2.0 + 2.5) * 100 = 35.7\% \\ \text{Weight for P2 (Wt P2)} &= 1.0/(1 + 1.5 + 2.0 + 2.5) * 100 = 14.3\% \\ \text{Weight for P3 (Wt P3)} &= 2.0/(1 + 1.5 + 2.0 + 2.5) * 100 = 28.5\% \\ \text{Weight for P4 (Wt P4)} &= 1.5/(1 + 1.5 + 2.0 + 2.5) * 100 = 21.4\%.\end{aligned}$$

The final weights shown in Table 4.12 are determined by rounding each of the weights calculated above to the nearest multiple of five (5). Finally, the INI for each work process is determined as follows:

$$\text{INI} = \text{Score P1} * 35\% + \text{Score P2} * 15\% + \text{Score P3} * 30\% + \text{Score P4} * 20\%$$

Table 4.12: Integration Need Index (INI) parameter scoring

Parameters	Weights	Explanation	Scale Values		
			L=1	M=5	H=10
No. of Exchanged DE in WP	30%	Total count of DE within WP	1	2-3	>=4
% of Non-Digital DE Exchanged in WP	15%	Percentage of non-digital DE of total count within WP	0-33%	34-66%	66-100%
No. of Different Users in WP	35%	No. of different primary and secondary users within WP	Same Primary Users (SPU)	Different Primary Users (DPU)	Different Organizations (DO)
No. of Different Tools used in WP	20%	No. of different tools within WP	2	3-4	>=5
Integration Need Index	= Weighted average of parameters				

Integration Capability Index Calculation

The Integration Capability Index (ICI) is calculated by dividing the number of integration links used between tools on a WP by the number of integration links between tools that are provided by the tool developers. This score is normalized by using the scale shown in Table 4.13.

Table 4.13: Integration Capability Index (ICI) scoring

Parameters	Explanation	Scale Values		
		1	2-9	10
Integration Capability Index	(No. of Existing Links/No. of Possible Links Between Tools)*10	0.0 - 1.0	2-9	10.0 or 0/0

4.3 Sample IT Integration Gap Assessment

The following is an explanation on how to read the data model analysis table for each work process. The data model analysis table with parameter scores, INI's, and ICI's for WP1 and WP2 is shown in Table 4.14. WP1 consists of work function (WF) L2-1.2 and WF L2-1.3. Data elements (DE) 3, 4 and 5 are transmitted within this WP. The user EN (engineer/design consultant) is responsible for WF L2-1.2, and EN (engineer/design consultant) is also responsible for WF L2-1.3. Tools T8 and T9 are used on WF L2-1.2, and tool T23 is used on WF L2-1.3.

Next, each parameter is given a raw score. The result of this evaluation is the first number shown in columns 8 through 11 in Table 4.14. The raw scores for each parameter in WP1 are:

- No. of Exchanged DE in WP = 3
- Percent (%) of Non-Digital DE Exchanged in WP = 100%
- No. of Different Users in WP = Same Primary User (SPU)
- No. of Different Tools Used on WP = 3

Table 4.12 is used to normalize the raw score of each parameter. The normalized score is the second value shown in columns 8 through 11 in Table 4.14. The resulting normalized scores are:

- No. of Exchanged DE in WP: Score = 5;
- Percent (%) of Non-Digital DE Exchanged in WP: Score = 10;
- No. of Different Users in WP: Score = 1;
- No. of Different Tools Used on WP: Score = 5.

Finally, the INI for WP1 is calculated and rounded up as follows:

$$\text{INI for WP1} = 5 * 0.3 + 10 * 0.15 + 1 * 0.35 + 5 * 0.2 = 4.$$

To calculate the Integration Capability Index, the number of possible integration links between tools must first be determined. In this illustration, no links exist between tools T8, T9 and T2 (see Tables 4.2 through 4.6 for a list of IT tool links). Therefore, the number of possible links between tools is zero (0). As a result, the ICI is calculated as follows:

$$\text{No. of existing links / no. of possible links between tools} = 0 / 0 = 0,$$

so per Table 4.13, ICI = 1.

The method just described is used to calculate the INI and ICI for every work process shown on the data model.

Table 4.14: Example data model analysis table for WP1 and WP2

CHAPTER 5 SPECIFICATIONS FOR ENHANCED INTEGRATION

5.1 High Priority Integration Strings

After conducting the integration gaps analysis on every work process on the data models, the results are summarized in this chapter. Each WP is plotted on the need vs. capability diagram (Figure 5.1) according to each WP's Integration Need Index (INI) and Integration Capability Index (ICI).

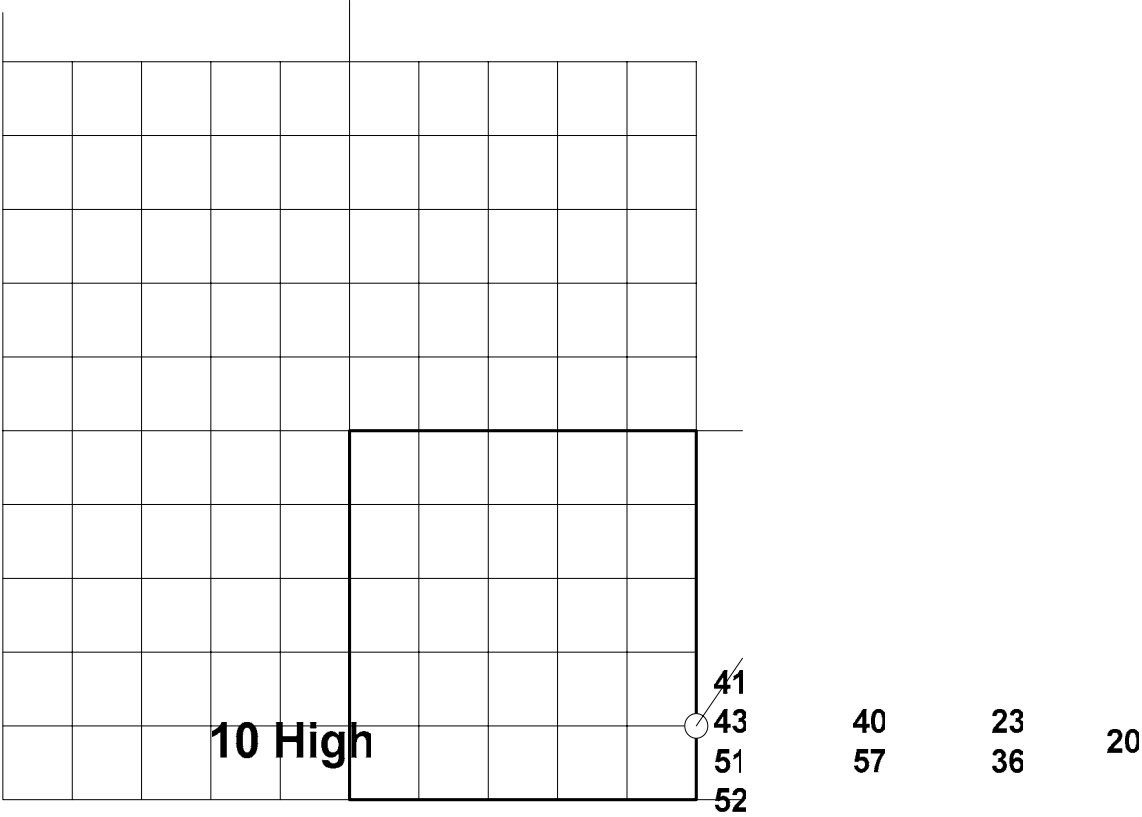


Figure 5.1: WP integration need vs. capability diagram

n Capability

5 Medium

WP's with an INI greater than five (5) and an ICI less than five (5) are high priority integration strings and can be found in the highlighted quadrant in Figure 5.1. These WPs, summarized in Tables 5.1 and 5.2, have been selected for further analysis.

Table 5.1: Selected high priority integration strings

Selected WP No.	Links WF	Name	To WF	Name	Data Elements Exchanged
4	IIM	Infrastructure Information Management	L2-1.1	Water System Master Plan Analysis	Infrastructure Components Inventory, Population Growth, Commodity Rates, Water Supply Demand, Existing Hydraulic Models, Water Resources Availability
6	IIM	Infrastructure Information Management	L2-1.2	Alternative Pipeline Alignment Development	Other Utility Inventory & ROW, Hydrology, Geology, Available Topography, Existing Real Estate Information
8	L2-2.6	Preliminary Route Plans Development	L2-2.10	Preliminary Cost Estimate	Proposed Pipeline Length/Sections
15	L2-2.6	Preliminary Route Plans Development	L2-2.4	Route Survey	Route Coordinates
16	L2-2.6	Preliminary Route Plans Development	L2-2.5	Geotechnical Investigation	Route Coordinates
42	L2-2.5	Geotechnical Investigation	L2-3.5	Corrosion Protection System Selection	Soil Layers, Soil Properties, Groundwater Levels
45	L2-2.5	Geotechnical Investigation	L2-3.6	Support Structures Analysis & Design	Soil Layers, Soil Properties, Groundwater Levels
46	L2-3.7	Specifications Development	L2-3.8	Engineering Cost Estimate	Proposed Construction Method, Bedding Requirements, Pipe Type, CP System Type, Electrical System Type, Equipment Types

Table 5.2: Selected high priority integration strings – continued

Selected WP No.	Links WF	Name	To WF	Name	Data Elements Exchanged
47	L2-3.4	Plans & Profiles Development	L2-3.8	Engineering Cost Estimate	Pipe Lengths/Sections, Pipeline Depth
48	L2-3.9	Details Drawings Development	L2-3.8	Engineering Cost Estimate	Support Structure Dimensions
49	L2-2.6	Preliminary Route Plans Development	L2-3.1	Pipe Structural Analysis & Design	Proposed Pipeline Materials, Proposed Pipeline Length/Sections, Proposed Pipeline Depth
50	L2-2.5	Geotechnical Investigation	L2-3.1	Pipe Structural Analysis & Design	Soil Layers, Soil Properties, Groundwater Levels
55	L2-4.4	Project Cost Controls (OW)	L2-5.5	Project Cost Controls (DC)	Cost Updates
59	L2-4.3	Milestone Schedule Preparation & Controls	L2-5.4	Schedule Preparation & Controls	Progress Updates
various WP affecting	L2-3.1	Pipe Structural Analysis & Design	Quotes & Catalogs	RFQ Processes with Suppliers	various, see Data Model
	L2-3.5	Corrosion Protection System Selection			various, see Data Model
various WP affecting	L2-2.8	Controls Eqpt. Selection	Quotes & Catalogs	RFQ Processes with Supplier	various, see Data Model
	L2-3.3	Controls Eqpt. Selection II			various, see Data Model

The level 2 data models have been modified to graphically display the high priority integration strings by highlighting the links of the WP's that have been selected for further analysis. Figures 5.2 through 5.6 illustrate the selected integration strings.

Figure 5.2: Selected high priority integration strings in planning & feasibility

Figure 5.3: Selected high priority integration strings in site investigation & pre-design

Figure 5.4: Selected high priority integration strings in final design

Figure 5.5: Selected high priority integration strings in owner project administration

Figure 5.6: Selected high priority integration strings in DC project management

5.2 Specifications for Enhanced Integration

Specifications for enhanced integration of the selected work process have been developed and are shown in Figures 5.2 through 5.17. The integration strategies shown in Figure 5.7 were taken from those illustrated in Figure 3.1 and discussed in Chapter 3. For each high-priority integration string, a proposed approach is also provided in the specifications to further elaborate on specific methods for integration.

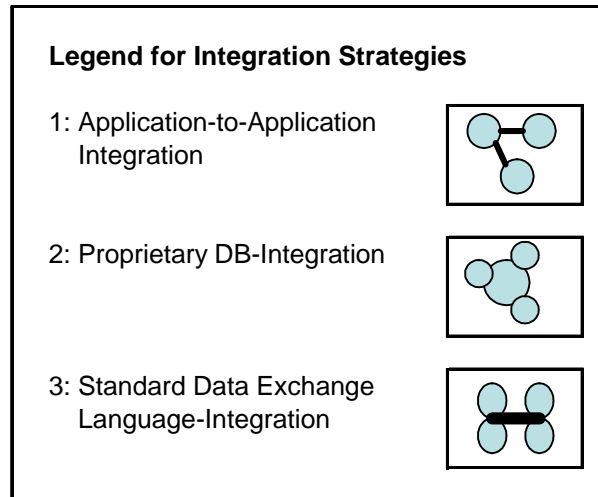


Figure 5.7: Legend for integration strategies

Data Integration String:		WP4	Recommendations:	
Links WF	<u>IIM</u>	to	<u>L2-1.1</u>	Proposed Approach:
Links Tool	<u>T1, T2, T3, T4, T23</u>	to	<u>T5, T6, T7</u>	1: Application-to-Application Integration
Links User	<u>OW</u>	to	<u>DC/EN</u>	Add New Tool:
Data Elements Transferred:			<u>IE1, GE1-5, OM1-5</u>	Modify Existing Tool:
Party Best Suited for Development:	<u>3rd Party</u>			
Descriptive Scenario:				
Develop databases that contain data elements transferred in digital format, i.e. all growth and economics (GE) and operations & maintenance (OM) data elements. Integrate with hydraulic modeling to forecast future capital improvement needs.				

Figure 5.8: Specifications for WP4

Data Integration String:		WP6	Recommendations:	
Links WF	<u>IIM</u>	to	<u>L2-1.2</u>	Proposed Approach:
Links Tool	<u>T5, T6, T7</u>	to	<u>T8, T9</u>	1: Application-to-Application Integration
Links User	<u>OW</u>	to	<u>DC/EN</u>	Add New Tool:
Data Elements Transferred:			<u>IE2, IE3, IE5, IE6</u>	Modify Existing Tool:
Party Best Suited for Development:	<u>OW/In-house</u>			
Descriptive Scenario:				
Enter more existing infrastructure and ROW information into GIS. Share more utilities and infrastructure information (wastewater, telecom, gas, transportation) between stakeholders to allow for enhanced decision making in early planning stages and minimize need for field surveys. Provide access to data for design consultants through Internet				

Figure 5.9: Specifications for WP6

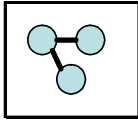
Data Integration String:		WP8	Recommendations:		
Links WF	<u>L2-2.6</u>	to	<u>L2-2.10</u>	Proposed Approach: 1: Application-to-Application Integration	
Links Tool	<u>T8, T9</u>	to	<u>T23, T41, T42</u>		
Links User	<u>DC/CT</u>	to	<u>DC/ES</u>		
Data Elements Transferred:			<u>21</u>	Add New Tool:	<input type="text"/>
				Modify Existing Tool:	<input checked="" type="checkbox"/>
Party Best Suited for Development: <u>3rd Party</u>					
Descriptive Scenario:					
Use linear quantity take-off functions in CADD tools to determine pipeline section estimating parameters such as pipeline lengths and proposed construction methods. Import quantities from preliminary CADD plan files into estimating tool spreadsheet cells.					

Figure 5.10: Specifications for WP8

Data Integration String:		WP15	Recommendations:		
Links WF	<u>L2-2.6</u>	to	<u>L2-2.4</u>	Proposed Approach: 1: Application-to-Application Integration	
Links Tool	<u>T8, T9</u>	to	<u>T8, T9, T12, T13</u>		
Links User	<u>DC/CT</u>	to	<u>Sub</u>		
Data Elements Transferred:			<u>29</u>	Add New Tool:	<input type="text"/>
				Modify Existing Tool:	<input checked="" type="checkbox"/>
Party Best Suited for Development: <u>3rd-Party</u>					
Descriptive Scenario:					
Integrate and overlay Electronic Field Books (EFB) with preliminary CADD plans. Allow to surveying crews to automatically create Digital Terrain Models (DTM) in the field. Import preliminary plans into EFB and export complete DTM back into plans.					

Figure 5.11: Specifications for WP15

Data Integration String:		WP16	Recommendations:			
Links WF	<u>L2-2.6</u>	to	<u>L2-2.5</u>	Proposed Approach:		
Links Tool	<u>T8, T9</u>	to	<u>T23, T36-40</u>	1: Application-to-Application Integration		
Links User	<u>DC/CT</u>	to	<u>Sub</u>			
Data Elements Transferred:			<u>29</u>	Add New Tool:		
Party Best Suited for Development:	<u>3rd-Party</u>			Modify Existing Tool:		
<table border="1"> <tr><td>X</td></tr> <tr><td>X</td></tr> </table>					X	X
X						
X						
Descriptive Scenario:						
<p>Integrate and overlay Electronic Field Books (EFB) with preliminary CADD plans to automatically include boring locations. Connect soil analysis results such as boring logs, location nodes to preliminary plans for enhanced engineering decision making. Import preliminary plans into EFB and export updated plans back into master plans.</p>						

Figure 5.12: Specifications for WP16

Data Integration String:		WP42	Recommendations:			
Links WF	<u>L2-2.5</u>	to	<u>L2-3.5</u>	Proposed Approach:		
Links Tool	<u>T36 - T40,</u> <u>T23</u>	to	<u>T23</u>	1: Application-to-Application Integration		
Links User	<u>Sub/EN</u>	to	<u>DC/EN</u>			
Data Elements Transferred:			<u>33, 34, 35</u>	Add New Tool:		
Party Best Suited for Development:	<u>In-house</u>			Modify Existing Tool:		
<table border="1"> <tr><td></td></tr> <tr><td>X</td></tr> </table>						X
X						
Descriptive Scenario:						
<p>Integrate geotechnical analysis data with corrosion protection system design tools to reflect subsurface conditions in design and analysis.</p>						

Figure 5.13: Specifications for WP42

Data Integration String:		WP45	Recommendations:	
Links WF	<u>L2-2.5</u>	to	<u>L2-3.6</u>	Proposed Approach:
Links Tool	<u>T36 - T40,</u> <u>T23</u>	to	<u>T23, T24</u>	1: Application-to-Application Integration
Links User	<u>Sub/EN</u>	to	<u>DC/EN</u>	Add New Tool:
Data Elements Transferred:			<u>33, 34, 35</u>	Modify Existing Tool:
Party Best Suited for Development:	<u>In-house</u>			
Descriptive Scenario:				
Integrate geotechnical analysis data with structural design tools to reflect subsurface conditions in design and analysis.				

Figure 5.14: Specifications for WP45

Data Integration String:		WP46	Recommendations:	
Links WF	<u>L2-3.7</u>	to	<u>L2-3.8</u>	Proposed Approach:
Links Tool	<u>T22</u>	to	<u>T23, T41,</u> <u>T42</u>	1: Application-to-Application Integration
Links User	<u>EN</u>	to	<u>ES</u>	Add New Tool:
Data Elements Transferred:			<u>27, 37,</u> <u>45, 54,</u> <u>59, 61</u>	Modify Existing Tool:
Party Best Suited for Development:	<u>3rd Party</u>			
Descriptive Scenario:				
Link specification entries such as quantities and material/equipment types with cells in estimating tool spreadsheet cells.				

Figure 5.15: Specifications for WP46

Data Integration String:		WP47	Recommendations:	
Links WF	<u>L2-3.4</u>	to	<u>L2-3.8</u>	Proposed Approach:
			<u>T42</u>	1: Application-to-Application Integration
Links Tool	<u>T8, T9</u>	to	<u>T23, T41,</u>	
Links User	<u>CT</u>	to	<u>ES</u>	Add New Tool:
Data Elements Transferred:			<u>43, 63</u>	Modify Existing Tool:
				<input checked="" type="checkbox"/>
Party Best Suited for Development: <u>3rd Party</u>				
Descriptive Scenario:				
Use standard pipe bedding and installation details and quantity take-off functions in CADD tools to establish estimating parameters. Import quantities from CADD plan & profile files into estimating tools' spreadsheet cells.				

Figure 5.16: Specifications for WP47

Data Integration String:		WP47	Recommendations:	
Links WF	<u>L2-3.4</u>	to	<u>L2-3.8</u>	Proposed Approach:
			<u>T42</u>	1: Application-to-Application Integration
Links Tool	<u>T8, T9</u>	to	<u>T23, T41,</u>	
Links User	<u>CT</u>	to	<u>ES</u>	Add New Tool:
Data Elements Transferred:			<u>43, 63</u>	Modify Existing Tool:
				<input checked="" type="checkbox"/>
Party Best Suited for Development: <u>3rd Party</u>				
Descriptive Scenario:				
Use standard pipe bedding and installation details and quantity take-off functions in CADD tools to establish estimating parameters. Import quantities from CADD plan & profile files into estimating tools' spreadsheet cells.				

Figure 5.17: Specifications for WP48

Data Integration String:		WP49	Recommendations:	
Links WF	<u>L2-2.6</u>	to	<u>L2-3.1</u>	Proposed Approach:
Links Tool	<u>T8, T9</u>	to	<u>T23, T24</u>	1: Application-to-Application Integration
Links User	<u>CT</u>	to	<u>EN</u>	
Data Elements Transferred:			<u>20, 21</u>	Add New Tool:
				Modify Existing Tool:
Party Best Suited for Development:	<u>In-house</u>			
Descriptive Scenario:				
Import quantities from CAD plan & profile files into estimating tool spreadsheet cells.				

Figure 5.18: Specifications for WP49

Data Integration String:		WP50	Recommendations:	
Links WF	<u>L2-2.5</u>	to	<u>L2-3.1</u>	Proposed Approach:
	<u>T23,</u>			1: Application-to-Application Integration
Links Tool	<u>T36 - T40</u>	to	<u>T23, T24</u>	
Links User	<u>Sub/EN</u>	to	<u>DC/EN</u>	Add New Tool:
Data Elements Transferred:			<u>33, 34, 35</u>	Modify Existing Tool:
Party Best Suited for Development:	<u>In-house</u>			
Descriptive Scenario:				
Import geotechnical analysis data into design tools for entering subsurface conditions in design and analysis.				

Figure 5.19: Specifications for WP50

Data Integration String:		WP55	Recommendations:	
Links WF	<u>L2-4.4</u>	to	<u>L2-5.5</u>	Proposed Approach:
Links Tool	<u>T3, T31, T49</u>	to	<u>T29, T31, T32</u>	2: Proprietary DB-Integration
Links User	<u>OW</u>	to	<u>DC/PM</u>	
Data Elements Transferred:			<u>70</u>	Add New Tool:
				Modify Existing Tool:
				<input checked="" type="checkbox"/>
Party Best Suited for Development: <u>PM/In-house</u>				
Descriptive Scenario:				
Integrate utility and consultants cost controls systems for program management. Link cost controls tools with utility's proprietary database to store, retrieve and manipulate cost information. Develop macros for cost controls tools to provide access to database through Internet.				

Figure 5.20: Specifications for WP55

Data Integration String:		WP59	Recommendations:	
Links WF	<u>L2-4.3</u>	to	<u>L2-5.4</u>	Proposed Approach:
Links Tool	<u>T3, T49</u>	to	<u>T25, T26, T27</u>	2: Proprietary DB-Integration
Links User	<u>OW</u>	to	<u>DC/PM</u>	
Data Elements Transferred:			<u>71</u>	Add New Tool:
				Modify Existing Tool:
				<input checked="" type="checkbox"/>
Party Best Suited for Development: <u>PM/In-house</u>				
Descriptive Scenario:				
Integrate utility and consultants scheduling systems for program management. Link schedule tools with utility's proprietary database to store, retrieve and manipulate schedule information. Develop macros for scheduling tools to provide access to database through Internet.				

Figure 5.21: Specifications for WP59

Data Integration String:		various	Recommendations:	
Links WF	<u>L2-2.8,</u> <u>L2-3.3</u>	to	<u>Quotes &</u> <u>Cataloges</u>	Proposed Approach:
Links Tool	<u>(-)</u>	to	<u>(-)</u>	3: Standard Data Exchange Language-Integration
Links User	<u>EN</u>	to	<u>SP</u>	Add New Tool:
Data Elements Transferred:	<u>various</u>			Modify Existing Tool:
Party Best Suited for Development: <u>SP/In-house</u>				
Descriptive Scenario:				
Develop Internet-based product catalogs that help design consultant select appropriate equipment. Web catalogs should include digital versions of specifications texts and 3D cut-sheets with dimensions. Use XML standard to transmit data. Link data from equipment selection to other tools (plans development, specification development, details development).				

Figure 5.22: Specifications for various WP

Data Integration String:		various	Recommendations:	
Links WF	<u>L2-3.1</u> <u>L2-3.5</u>	to	<u>Quotes &</u> <u>Cataloges</u>	Proposed Approach:
Links Tool	<u>(-)</u>	to	<u>(-)</u>	3: Standard Data Exchange Language-Integration
Links User	<u>EN</u>	to	<u>SP</u>	Add New Tool:
Data Elements Transferred:	<u>various</u>			Modify Existing Tool:
Party Best Suited for Development: <u>SP/In-house</u>				
Descriptive Scenario:				
Develop Internet based product catalogs that help design consultant select appropriate pipe materials & corrosion protection. Web catalogs should include digital versions of specifications texts and cut-sheets with dimensions where needed. Use XML standard to transmit data. Link data from selection process to other tools (plans development, specification development, details development).				

Figure 5.23: Specifications for various WP

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CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study has been an attempt at systematically analyzing and identifying high priority IT tools integration strings in water transmission project planning and design. Since integration of IT automation islands is the next paramount step to increased project performance, the analyses on closing existing IT tools integration gaps presented in this document is both important and timely.

It has been shown that the work processes and IT tools of a particular industry can be analyzed to qualitatively assess IT integration needs within capital facility delivery projects. Only work processes with high integration needs and low integration capabilities were selected for further analysis. The selected work processes are presented in Tables 6.1 and 6.2.

Table 6.1: High priority integration strings

Selected WP No.	Links WF	Name	To WF	Name	Data Elements Exchanged
4	IIM	Infrastructure Information Management	L2-1.1	Water System Master Plan Analysis	Infrastructure Components Inventory, Population Growth, Commodity Rates, Water Supply Demand, Existing Hydraulic Models, Water Resources Availability
6	IIM	Infrastructure Information Management	L2-1.2	Alternative Pipeline Alignment Development	Other Utility Inventory & ROW, Hydrology, Geology, Available Topography, Existing Real Estate Information
8	L2-2.6	Preliminary Route Plans Development	L2-2.10	Preliminary Cost Estimate	Proposed Pipeline Length/Sections
15	L2-2.6	Preliminary Route Plans Development	L2-2.4	Route Survey	Route Coordinates
16	L2-2.6	Preliminary Route Plans Development	L2-2.5	Geotechnical Investigation	Route Coordinates
42	L2-2.5	Geotechnical Investigation	L2-3.5	Corrosion Protection System Selection	Soil Layers, Soil Properties, Groundwater Levels
45	L2-2.5	Geotechnical Investigation	L2-3.6	Support Structures Analysis & Design	Soil Layers, Soil Properties, Groundwater Levels
46	L2-3.7	Specifications Development	L2-3.8	Engineering Cost Estimate	Proposed Construction Method, Bedding Requirements, Pipe Type, CP System Type, Electrical System Type, Equipment Types

Table 6.2: High priority integration strings – continued

Selected WP No.	Links WF	Name	To WF	Name	Data Elements Exchanged
47	L2-3.4	Plans & Profiles Development	L2-3.8	Engineering Cost Estimate	Pipe Lengths/Sections, Pipeline Depth
48	L2-3.9	Details Drawings Development	L2-3.8	Engineering Cost Estimate	Support Structure Dimensions
49	L2-2.6	Preliminary Route Plans Development	L2-3.1	Pipe Structural Analysis & Design	Proposed Pipeline Materials, Proposed Pipeline Length/Sections, Proposed Pipeline Depth
50	L2-2.5	Geotechnical Investigation	L2-3.1	Pipe Structural Analysis & Design	Soil Layers, Soil Properties, Groundwater Levels
55	L2-4.4	Project Cost Controls (OW)	L2-5.5	Project Cost Controls (DC)	Cost Updates
59	L2-4.3	Milestone Schedule Preparation & Controls	L2-5.4	Schedule Preparation & Controls	Progress Updates
various WP affecting	L2-3.1	Pipe Structural Analysis & Design	Quotes & Catalogs	RFQ Processes with Suppliers	various, see Data Model
	L2-3.5	Corrosion Protection System Selection			various, see Data Model
various WP affecting	L2-2.8	Controls Eqpt. Selection	Quotes & Catalogs	RFQ Processes with Supplier	various, see Data Model
	L2-3.3	Controls Eqpt. Selection II			various, see Data Model

The main areas of IT tools disconnectivity that can be further summarized from Table 6.1 and 6.2, are:

- Limited digital data sharing between utilities and public work departments during capital improvement planning, resulting in less effective decision making by design consultants in the early stages of the project;
- No digital data exchange between CADD-based pipeline route development and structural analysis of pipeline components;
- Disconnections between pipeline route drafting/design and cost estimating tools are apparent in the missing links between CADD-based route development and manual quantity take-off;

- Request-For-Quotes (RFQ) processes, for example commonly exclude functionality pertaining to requesting, receiving, and using suppliers' data in digital format, thus disconnecting all work functions in which the information is needed;
- Disconnected owner and design consultant project controls systems.

The integration gaps analysis concluded by presenting integration approaches for each work process. Applying an application-to-application integration approach is considered most suitable for closing the identified IT integration gaps. It was suggested that IT tool developers provide enhanced Import/Export functionality for major IT tools such as GIS, CADD and estimating. Integration efforts with a smaller scope, such as connecting structural design software with CADD, can be achieved in-house by using the programming capabilities available within most IT tools. The integration of project controls systems such as cost controls and scheduling can be achieved by developing proprietary databases with the help of program managers with in-house IT capabilities.

The study revealed that the IT tool integration gaps presented in this study partly exist due to the fact that a few large automation islands dominate. Furthermore, standard data exchange protocols for engineering and construction are far from being implementable. In addition, most integration efforts are still software developer driven. Only in rare instances do software users invest independently in integrating these large automation islands, since the costs and benefits of integrated project processes are difficult to ascertain.

6.2 Recommendations

Findings from this study suggest the following recommendations for future research efforts:

- Perform detailed benefits analysis for closing integration gaps, i.e. work productivity improvements and cost savings expected from improved decision-making and design deliverables should be quantified in further studies;
- Further define specific new and modified tools that enable integrated project processes with assistance from software developers and design consultants;
- Extend scope and re-apply the established methodology to other project phases and industries.

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LIST OF STUDY PARTICIPANTS

City of Houston, Department of Public Works and Engineering, Houston, TX

Freese & Nichols, Fort Worth, TX

CH2M Hill, Greenwood Village, CO