

An Advanced Construction Supply Nexus Model

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The complex and challenging process of construction supply chain management can involve tens of thousands of engineered components, systems, and subsystems, all of which must be designed in a multi-party and collaborative environment, the complexity of which is vastly increased in the case of megaprojects. A comprehensive Advanced Construction Supply Nexus Model (ACSNM) was developed as a computational and process-oriented environment to help project managers deal efficiently and effectively with supply chain issues: fragmentation, resource shortages, design delays, and planning and scheduling deficiencies, all of which result in decreased productivity, cost and time overruns, conflicts, and time-consuming legal disputes.

To mitigate the effects of these difficulties, four new prototype systems are created: a front-end planning tool (FEPT), a construction value packaging system (CVPS), an integrated construction materials management (ICMM) system, and an ACSNM database. Because these components are closely interdependent elements of construction supply nexus management, the successfully developed model incorporates cross-functional integration. This research therefore effectively addresses process management, process integration, and document management, features not included in previous implementations of similar models for construction-related applications. This study also introduces new concepts and definitions, such as construction value packages comprised of value units that form the scope of value-added work defined by type, stage in the value chain, and other elements such as drawings and specifications.

The application of the new technologies and methods reveals that the ACSNM has the potential to improve the performance and management of the enterprise-wide supply chain. Through opportunities provided by our industry partners, Coreworx Inc. and Aecon Group Inc., the elements of the developed model have been validated with respect to implementation using data from several construction megaprojects. The model is intended to govern current supply nexus processes associated with such megaprojects but may be general enough for eventual application in other construction sectors, such as multi-unit housing and infrastructure.

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Dedication

This thesis is dedicated to my wife, Maryam, and my son, Parsa, who have always stood by me!

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Chapter 1

Introduction

1.1 Background and Motivation

Supply chain management and other similar terms, such as Interim Product Database (IPD), network sourcing, supply pipeline management, value chain management, and value stream management, have become subjects of increasing interest to academics, consultants, and business management (Croom et al., 2000). In the construction industry, supply chain management, which is interdisciplinary in nature, has traditionally been called construction supply chain management (CSCM) and is today a separate and distinct discipline. Its definition is based on the nature of construction projects and encompasses the planning and management of most activities and processes related to a project. The scope, role, and methods of CSCM may have changed over the years, but its purpose remains the same: ensuring that the goals of a construction project are met and that productivity and efficiency are maximized.

In industrial construction, the concept of materials management is closely related to supply chain management. In the Construction Industry Institute's (CII's) *The Global Procurement and Materials Management Handbook: An e-Guide for Effective Project Execution* (2009), the key elements of modern materials management are identified, and the related processes are defined in detail: (1) personnel and organization, (2) materials requirement planning, (3) project acquisition strategy, (4) purchasing, (5) subcontracting, (6) expediting, (7) supplier quality management, (8) transportation and logistics, (9) site warehousing and materials, and (10) planning for operations and maintenance. A sub-category of construction supply nexus management is construction materials management, which is defined in this thesis as the process of planning, allocating, and controlling resources and value additions. The drive toward managing procurement and the supply nexus in a process-based manner, enabled by information technology systems and with metrics for progress tracking, is creating a compelling need for the development of an Advanced Construction Supply Nexus Model (ACSNM).

The term “nexus” is introduced here to refer to a series of interfaces (links) among multiple stakeholders during the construction supply chain process. In this context, the term “supply nexus management” is preferred over the more traditional “supply chain management” in order to emphasize a close association with software-based models.

The inherent variability in construction is the basis for the significant challenges encountered in the implementation of SCM techniques in the construction industry. Much of the uncertainty associated with a project, however, arises from a lack of accurate, readily available information, such as the status of materials at different stages within the construction supply network. In other words, the construction industry generally lacks supply network visibility. The key to improving visibility is the sharing of information between supply network members (Christopher and Lee, 2004; Delen et al., 2007). In this regard, an ACSNM system offers tremendous potential for improving supply chain visibility and for providing possible solutions to future problems related to supply nexus and materials management.

The vision of future supply nexus management contrasts with past conditions in several ways. Because of the drift toward prefabrication, value is added earlier in the supply chain (Sacks et al., 2004). Improvements are also evident in information-technology-enabled, web-based collaboration, automation, integration, product and process management, and project performance, with ACSNM playing a key role.

1.2 Research Objectives

The construction industry is becoming increasingly concerned about the failure of construction supply nexus management to result in the achievement of project goals in spite of the impressive technologies available and the considerable resources allocated. Specific gaps exist in the theoretical and empirical research with respect to some aspects of advanced construction supply management, especially the value package system, which should be integrated with other elements of the supply chain, including the material management system and contract management.

Bridging the gap between construction experts, engineers, manufacturers, and researchers requires the development of a model and a framework that can be used by all stakeholders through a common platform and using common terminology. The primary goal of the research presented in this thesis is to develop an ACSNM using a front-end planning tool (FEPT), a construction value package system (CVPS), and an integrated construction materials management (ICMM) system. The developed model serves as a computational and process environment that facilitates decision-making processes for a variety of levels and phases of a construction project in order to promote efficiency, effectiveness, and objectivity.

The systems and tools created through this research enable the use of an ACSNM to provide improvements in the performance and management of an enterprise-wide supply chain system. Such a system has the potential to organize diverse activities by building a strongly integrated framework for effective supply nexus management and by providing common terminology and standard process descriptions. The following sub-objectives guided the work that led to the completion of the primary research objective:

1. Develop a framework and ontology for the integration and automation of the construction supply nexus processes. The construction supply nexus should improve the integration of the design, procurement, construction and materials management processes. This model must also increase supply chain visibility.
2. Develop a front-end planning (FEP) system for the management and facilitation of the strategic planning process. The FEP phase must involve a tool that functions as support for owners and major contractors who are engaged in FEP.
3. Develop a construction value packaging system. This system should operate as a tool for improving the efficiency of the contracting process by decreasing the time required for a decision and by generating options that may not otherwise be identified.
4. Improve project materials management processes and direct owner control of the procurement process through developing an integrated material management system. The developed system should formalize and manage the materials management processes, with the objectives of reducing inventory and waste with respect to site materials, expediting delivery, and providing increased control of materials, all of which are instrumental in decreasing the cost of a construction project.

1.3 Research Scope

Several managerial systems are in use in other industries, but the theories, methods, and results related to these industries cannot always be applied directly to the construction industry with the same level of success. Although several valuable tools and models have been developed, the literature contains no reports of a comprehensive model for the planning and management of construction supply nexus processes, from FEP to the construction phase.

The scope of this research focuses precisely on industrial sector projects in the construction industry, but the concepts and models developed are applicable to other construction industry sectors. In

general, the industrial construction sector involves projects such as power plants, refineries, and process facilities. It is characterized by a high concentration of participants, by owners who build frequently, by the involvement of trades such as pipefitters and millwrights, and by a high level of engineering and project management sophistication. The research presented in this thesis concentrates on industrial construction and, in particular, on megaprojects. The characteristics of megaprojects and other classes of construction projects are discussed in Chapter 2.

Because of time limits and other constraints, for validation purposes, the step-by-step verification approach was used for the development and implementation of the model as a whole with respect to a mega construction project. This research was coordinated and the model was validated in co-operation with Coreworx Inc., headquartered in Kitchener, Ontario, and with Aecon Group Inc. Industrial Division in Cambridge, Ontario.

1.4 Research Methodology

The methodology of this research is shown schematically in Figure 1-1. The model presented in this thesis is based on an iterative process of literature review; structure development; and eventually, the deployment of and experimentation with data from full-scale construction megaprojects. This process required seven steps in order to achieve the research goals. The first step was a review of the literature, concentrating on construction strategic management, construction management tools and methods, innovative techniques, the supply network, work packaging, construction bidding processes, and construction materials management.

The literature review, which is based on research reports, journals, books, and other sources, clearly identifies knowledge gaps that should be filled if the construction supply chain process is to be improved.

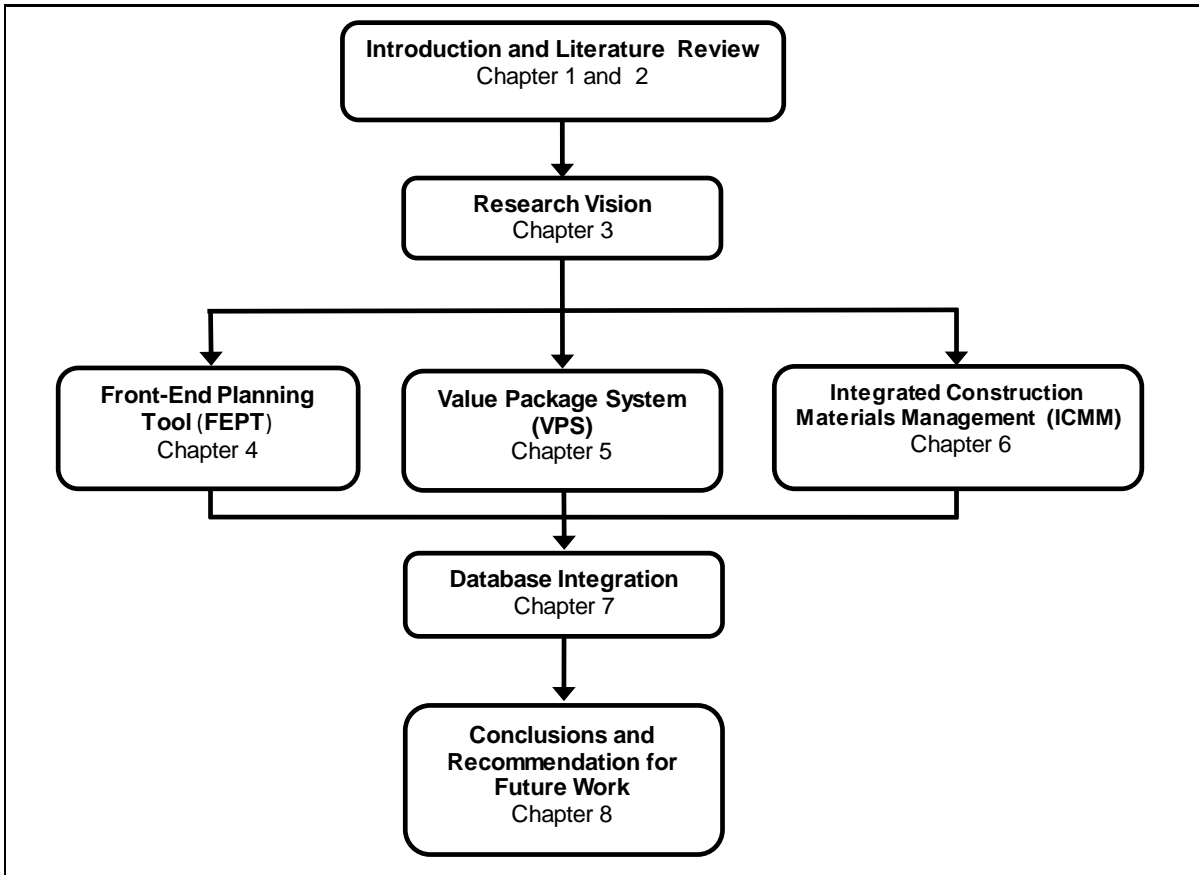


Figure 1-1: Research Components

1.5 Structure of the Thesis

Chapter 1 summarizes the research problem and describes the motivation, objectives, scope, and methodology of the research, along with the structure of the thesis. Chapter 2 provides the literature review, including a comparison of supply nexus management tools and models with previous models with respect to their ability to produce streamlined communication, integration and accelerated response times. The detailed review of the literature related to all of the research topics associated with the development of the model was the basis for the determination of the most feasible means through which new technologies and tools could be used for the model.

Chapter 3 presents the overall research approach and an overview of all elements of the model presented in this thesis, which addresses the knowledge gaps related to the lack of a comprehensive supply nexus model. The ACSNM developed in this research can be used to help integrate design, procurement, and materials management processes and to facilitate the optimization of supply chain

processes. In other words, the ACSNM encompasses important processes, including design, procurement, bidding, materials flow, logistics, purchasing, inventory flow scheduling and control, transportation systems operation, and some parts of infrastructure management.

Four core elements of the model developed in this research are then described in Chapters 4 to 7. The first element of the model is the Front End Planning Tool (FEPT). Chapter 4 explains its components, the recommendations that guided its development, its implementation, and its validation based on its application for three megaprojects. Generally, once all of the FEP steps are completed, the construction value packages can be developed; however, the completion of some packages also requires design information. The concept of the construction value package is defined in Chapter 5, which describes the construction value packaging system (CVPS) that was developed for this research.

The CVPS could not have been developed without strong and structured strategic planning based on a robust FEPT or without an Integrated Construction Material Management (ICMM) system, which is an important element of the new model. In Chapter 6, this system is presented as part of a construction packaging approach for the procurement phase of construction megaprojects. This chapter also identifies the taxonomy according to which the ICMM is used to formalize the materials management processes, thus helping to assure the quality and execution of these processes by forcing consistency, repeatability, responsibility, and accountability.

Chapter 7 discusses the requirements of the ACSNM database and presents an analysis of the findings. The final chapter of this thesis includes the conclusions and contributions, along with recommendations for potential future investigation of improvements to the model. Additional materials (forms, software coding, GUIs, contractor's sample information, and glossary of terms) are included in the appendices.

Chapter 2

Literature Review

This chapter provides a review and summary of the scholarly works whose concepts inform the research presented in this thesis. The discussion covers a synthesis of current knowledge and the gaps between the existing construction supply chain practices and the desired model, as illustrated through an integrated construction project management model for the industrial construction sector. The material is arranged thematically so that it corresponds to the steps involved in this research. While some articles and studies were more heavily drawn on than others, and some provided a direction for reflection rather than actual concepts, all of the works cited provided insights that proved valuable in the development of the model. The most significant outcome of the review was that it brought into sharp focus the need for a comprehensive model.

2.1 Introduction

Construction projects typically vary with respect to type and size and involve thousands of workers, millions of details, and countless complex variables, such as labour, materials, weather, and schedules. As a result, construction project managers constantly encounter problems such as fragmentation, resource and labor shortages, design delays, project delivery issues (Miller et al., 2000), and planning and scheduling deficiencies (Thompson and Lucko, 2012), all of which lead to low productivity, cost and time overruns, and conflicts that involve subsequent claims and time-consuming disputes (Hastak et al., 1996). Over the years, a variety of construction management practices have been developed in an attempt to address these challenges; however, no single integrated solution or model has been developed that addresses all of these challenges and their respective interfaces.

Construction as a whole is usually dominated by “one-off” projects (London, 1998; Vrijhoef and Koskela, 2000; Tah, 2005). That is, no individual project is identical to another and can even be more complex in different ways than any previously undertaken. This feature is relatively rare in other industries and is often termed “temporary multi-organization” (Koskela and Huovila, 1997). Supply chain management (SCM) is a popular operations paradigm that is used as the basis for coordinating supplies and managing suppliers for a construction project (Womack et al., 1990). SCM can be defined as the integration of key business processes so that suppliers provide appropriate products, services, and information and hence add value for clients and other stakeholders (Lambert et al.,

1998). The report of the Construction Task Force (Egan, 1998) concentrated on the need for the construction industry to improve the efficiency with which it operates its supply network. Attempts to enhance the current approach can take many forms, but current interest is in the incorporation of new methodologies and attitudes into the management of the construction supply network. The model presented in this study is focused on and addresses the knowledge gaps related to supply chain domains such as logistics, information flow, material and equipment management, workforce issues, and other specific areas as further described in this thesis.

The Construction Industry Institute (CII) and several scholars have found that approximately one-third of projects miss cost and scheduling targets and that a critical aspect of project underperformance in the construction industry is related to construction delays, which often result in legal claims and disputes (Anderson, 1990; Yeo and Ning, 2002; Johnson, 2011). One potential solution for these problems is the facilitation and improvement of the construction supply management process, which could help overcome classic problems related to the application of SCM principles in the construction industry, such as just-in-time delivery.

Several scholars have focused on a number of aspects of SCM and have introduced new tools and methods for improving current practices. For example, Tommelein (1998) was successful in demonstrating the theoretical ability of pull-driven scheduling as a means of enhancing the performance of the pipe spool installation process by reducing on-site material buffers. However, the difficulty in applying SCM concepts to construction projects results from the fundamental differences between manufacturing and construction (Prieto, 2009). Some practitioners and experts have striven to apply manufacturing supply chain models and techniques to the construction industry. Although these techniques have proven beneficial in establishing and maintaining construction supply chain models in some organizations, the construction supply chain must still be reconstructed and refurbished so that it incorporates the characteristics specific to the construction industry.

A key differentiator between construction and manufacturing industries is related to the constraints intrinsic to construction projects: weather, site conditions, site fabrication, the availability of resources, and local laws and regulations. Such factors have a minimal impact on the manufacturing industry but can have a highly unpredictable and variable effect on construction projects (Cox et al., 2006). Overall, it is the inherent presence of variability in construction that has complicated the application of SCM techniques for construction projects. For example, stockpiles of material and equipment are a regular sight on construction sites. In the case of industrial megaprojects, substantial

quantities of materials are accumulated in lay-down yards and warehouses prior to construction. The additional costs related to the accumulation and maintenance of these stockpiles can be enormous.

The development of a strengthened and reliable supply chain model requires that several driving concepts and methods be addressed: front-end planning (FEP) and other new construction tools, a work packaging system, an integrated materials management system, and web-based construction project governance. Some of these tools and concepts have been identified as a result of systemic innovations that require “multiple specialist firms to change their process in a coordinated fashion” (Taylor and Levitt, 2005). Most members of the construction industry have yet to acquire a thorough understanding of this type of innovation and the key prerequisites for its successful implementation. Despite low expenditures on systematic innovations and other new products in the construction industry, the significant technological improvements that have resulted from these innovations can demonstrate best practices for the construction industry and provide a basis for similar future projects.

The remainder of this chapter is structured to illustrate the foundation that was required for the development of the supply chain model presented in this thesis. To provide a meaningful and practical model, and in light of the vast differences among construction projects, the scope of the research needed to be defined, which in turn, required the adoption of a system for the classification of construction projects. Section 2.2 presents an overview of some of the existing classification systems for construction projects, followed by an explanation of the classification system that was developed for this study.

One of the research objectives is to improve project strategic planning, which takes place during the FEP stage of a project. Section 2.3 provides a comprehensive summary of the published literature related to improving FEP processes and identifies the knowledge gaps that exist in this area.

A primary focus of this research is to develop an alternative to existing construction work packaging systems, which would also effectively feed into the supply chain management system created through this work. To this end, a detailed analysis of existing construction work packaging systems, their strengths and weaknesses, and their required improvements was conducted and is documented in Section 2.4. A detailed review of materials management methods and concepts, as related to the construction industry, is then presented in section 2.5.

Finally, Section 2.6 summarizes a review of web-based project management tools, which are used in this research as the integration mechanism for the provision of effective and reliable lines of communication among all parties involved in the developed supply chain management model.

2.2 Classification of Construction Projects

The primary function of project classification is to allow scholars and experts to group construction projects according to similar characteristics. An adequate description of the scope of the model developed in this research required the adoption of a system for classifying construction projects. This section provides a summary of some of the most commonly used classification systems, followed by an explanation of the system adopted for this research.

Classification of the wide range of types of construction projects is especially challenging because of their one-off nature. For each category of projects, the construction project management process must provide the flexibility to choose a suitable level of planning and control for large, complex, high-risk, and new projects. For example, building information modeling (BIM) may not be appropriate for the budget and size of a small project. The grouping of construction projects plays a major role in the organization of the information related to specifications, the structuring of documents, and the calculation of costs. Tan and Lu (1993) grouped construction projects according to the type of construction work as follows:

Group A: roads, bridges, tunnels, railroads, rapid transit

Group B: petrochemical refineries, pipelines, power plants, *etc.*

Group C: steel plants, automobile plants, machinery shops, *etc.*

Group D: pharmaceutical plants, electronic plants, hospitals

Group E: food plants, textile plants, water plants, paper mills

Group F: additional types other than those listed above

Construction projects also can be classified into three main categories: industrial, public works and town planning, and buildings (Santana, 1990):

1. **Industrial:** nuclear power stations, solar power stations, steam power stations, hydroelectric stations, mining complexes, factories, gas and oil pipelines, industrial facilities, military establishments, industrial facilities, industrial pavement, water treatment plants, chemical

plants, offshore oil rigs, oil drilling rigs, refineries, silos and storage, power substations, power-line laying

2. **Public Works and Town Planning:** airports, roads and motorways, canals, caves and underground works, public and administrative buildings, railways, hospitals, earthworks, hydraulic installations, maritime stations, port works, irrigation works, urban transport, waterworks, dams, long-span bridges, harbours and decks, sewerage, underground public transport, tunnels
3. **Buildings:** shopping centres, health centres, education centres, housing estates, monument construction, office buildings, housing, parking garages, sport facilities, prefabrications

The goal of a construction project has been the focus of a variety of approaches that attempt to address project complexity. One proposed project classification system that considers complexity is shown diagrammatically in Figure 2-1 (Shenhar and et al., 1996). The three levels of complexity include assembly, system, and array. Assembly complexity represents a project that includes a collection of components and modules combined into a single unit. System complexity identifies a project that consists of a complex collection of interactive elements and subsystems within a single product, and array complexity signifies a program rather than a single project. In 2012, the CII launched a research team to study project complexity. It is considered to be a project aspect driving applicability of different management systems and processes such as interface and supply nexus management.

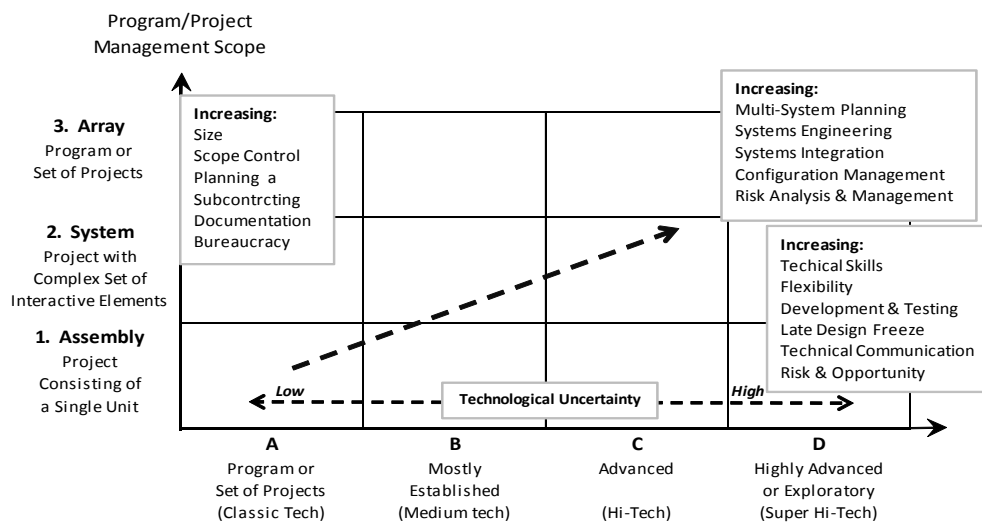


Figure 2-1: Project Classification Systems Based on Complexity (Shenhar and et al., 1996)

These types of categorization are advantageous, but construction projects exhibit numerous attributes or characteristics that could be used to define categories and to classify projects within an individual category. This consideration creates difficulty and results in a lack of a generally agreed-upon framework for classifying construction projects because of their uniqueness and their differences in terms of size, time, investment, complexity, and technological content. The reality is that fully categorizing construction projects is impossible, because they include unknown factors. The challenge is to select the most appropriate characteristics for defining the optimal categories for application of a supply chain model. For this study, construction projects are classified based on the published literature summarized above and with respect to their size, complexity, and risk tolerance. The classification includes consideration of four classes that have some overlap but that each involve a different level of detail:

1. Class I (megaprojects): This class refers to projects that have budgets exceeding \$1B and that require planning and execution over a very long term (more than three years). It includes government and national institutions, which have an enormous economic, social, and ecological impact.
2. Class II (large and unique): The investment in this class of project involves more than \$100M as well as long-term planning and execution (more than two years). These projects can share many of the class I features but are unique, with complicated management and implementation systems. Numerous contractors, specialists, and consultants are employed, and the most advanced technologies are used.
3. Class III (complex): This class requires middle-level planning and execution within a shorter time frame (one to three years). These projects usually have budgets between \$10M and \$100M. A complex project is not unique, and the problems involved are not complicated. Most industrial projects and many public works are categorized as complex (Santana, 1990).
4. Class IV (basic and normal): An investment of up to \$10M would be considered for this class of project. The projects are carried out with one year of planning or one budget period, with the use of measurable targets. Projects such as housing, earthworks, buildings, and roads can be considered class IV construction projects.

Throughout this research, when the terms “project,” “construction project,” or “construction megaproject” are used, a Class I project (megaproject) is implied.

2.3 Front-End Planning (FEP)

A construction project can be defined as a sequential activity that relies heavily on detailed planning and programming (Briscoe et al., 2001). Depending on their class, construction projects are prone to a variety of risks during strategic planning. In fact, many experienced managers consider construction supply nexus management to be essentially the art of initiating, defining, and managing the strategic plan. In most cases, long-term strategies for a new construction megaproject are established during the FEP, which is influenced by a number of constraints, such as resource limitations, government regulations, and environmental restrictions. This section introduces the concept of FEP and explores the knowledge gaps evident based on the existing literature, some of which have been addressed by the model presented in this thesis.

In construction, the strategic planning (FEP) process is associated with feasibility studies, sets of priorities, and timing considerations with respect to the initiation of all of the activities that will enable the overall objectives of the project to be met. This process may sound straightforward, but the research shows that many companies have overlooked the important aspect of aligning project performance with their strategic plans (Gibson et al., 1995; Bates, 1995; Cheah et al., 2004; Cheah and Chew, 2005; Whittington et al., 2009).

A study conducted by the City of Edmonton in which more than 200 capital construction projects were examined with respect to estimation accuracy revealed that only a small portion of projects actually fall within the desirable range of accuracy (AbouRizk, 1998; AbouRizk, 2000).

Traditionally, construction managers and decision makers have lacked the ability to appropriately plan, estimate, and execute projects in a consistent, efficient, effective, and reliable manner. The statistics related to cost and schedule overruns clearly indicate a general inability to accurately plan and estimate (AbouRizk, 1998; AbouRizk, 2000). The task of planning, prioritizing, and allocating funds is complex (Ariaratnam and MacLeod, 2002) and should be performed primarily during the FEP phase. For the research presented in this thesis, an attempt was made to shed light on how the use of a high-level engineering tool can enable project managers to conduct and manage the FEP phase more efficiently.

Research in the area of construction project planning, such as “pre-project planning” (Ford, Lander, and Voyer, 2002), “front-end loading” (Stacey, 2006), and “front-end planning” (Williams and Samset, 2010) has validated the hypothesis that effort spent on strategic project planning pays off in better project results and performance. CII research also confirms that FEP is a key factor in

improving project performance (CII, 2006). These studies show that managing a construction project well, based on a comprehensive strategic plan, leads to successful completion on schedule, within budget, and most importantly, within safety guidelines and with a minimal impact on the environment. Industry research also demonstrates that projects with rigorous FEP perform more than 10 % better in terms of cost, 7 % better with respect to schedule performance, and 5 % better relative to change orders than projects with little or no FEP (Gibson, 2010).

As mentioned with respect to the construction industry in general, no two FEP strategies can ever be exactly alike because of the dominant one-off nature of the projects (London et al., 1998; Vrijhoef, 2000; Tah, 2005) and the differentiation created by numerous constraints: weather, site conditions, site fabrication, and the availability of resources. Local laws and regulations can also be highly inconsistent and variable (Cox, 2006). For this reason, care must be taken to ensure that any model is flexible enough for use in most construction projects, given their specific characteristics and constraints, and any gaps that exist with respect to the execution of the model must be addressed.

One of the focuses of the literature review conducted for this research was the definition of FEP. CII defines it as “the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project” (CII, 1995). The emphasis is on creating a strong, early link between the needs or mission of the business and the strategy, scope, cost, and schedule associated with the project and on maintaining that link unbroken throughout the project life cycle (CII, 2008). Cleland and Ireland (2002) have expanded on this definition by stating that FEP is the process of thinking through and making explicit the goals and strategies required in order to bring a project through its life cycle to a successful conclusion when the project process is an appropriate part of the execution of the project owner’s strategies. FEP is also a critical process for revealing any unknowns that might arise during a project. The main deliverable of the FEP phase is an adequate level of design that enables the project team to prepare cost and schedule estimates and to identify risk.

Once project funding is approved, the FEP design deliverables become the primary input into the next phases in the project life cycle: procurement and detailed design. FEP gates and other life cycle project phases are shown in Figure 2-2. A gate is defined as the existence of the discrete information and definitions required for a decision that will determine whether to proceed.

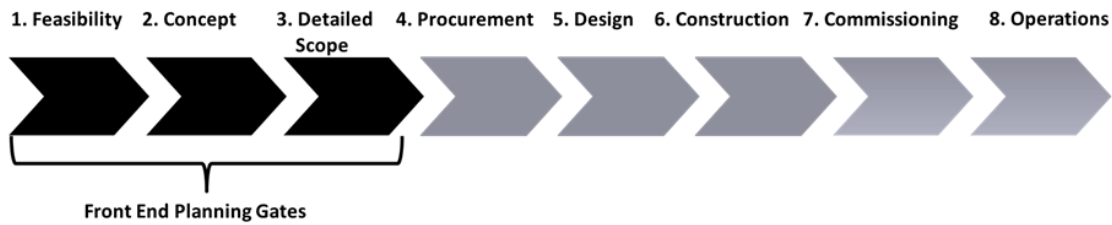


Figure 2-2: Front-End Planning and Project Life Cycle

The CII organized a planning research team whose assignment was to investigate the importance and value of FEP, to assess the resources required to perform the process effectively, and to make a draft of the rules that signify key sub-processes. They found that the FEP process resulted in savings that more than offset the level of investment required in systems, people, and other resources (Griffith et al., 2001). For capital construction projects (approximately >\$1B total installed value), the execution of FEP represents a major effort that involves many thousands of documents and a large team and that cannot be effectively managed through traditional spreadsheets, printed materials, and meeting minutes. Because FEP is a practice involving a diverse set of human interactions, information sources, and integrated processes, companies often fail to execute it consistently even when they commit to it. A strong need hence exists for a comprehensive engineering model or tool that addresses the requirements associated with this phase.

During the last decade, a revolution has occurred in other industries: business processes have been automated and enforced via the implementation of workflows embedded in corporate and institutional computing systems. Workflows are used most effectively for critical business processes that are subject to time constraints and to scrutiny for compliance with respect to regulated industry processes and human authorization. Examples include human resources management and product support processes. The construction industry is now catching up, and electronic product and process management systems are being developed that will enable the implementation of the workflow concept (Shokri et al., 2011). Workflows can be used to facilitate FEP.

Understanding the tools and methods used for managing the FEP project phase requires clarification of the terminology. In a number of industry segments and locales, practitioners have referred to these tools as Front-End Engineering Design (FEED) tools. A review of the related literature reveals that a number of companies use FEED as a descriptor for a wide variety of planning objectives and define FEED based on the specific objectives of their company. For this study, the term front-end planning tool (FEPT) was therefore selected in order to avoid confusion with other types of FEED tools.

The FEPT, the development and validation of which as described in Chapter 4 of this thesis, has not been the only practical tool that has been applied for managing FEP processes. A few companies have developed software models for directing and operating this phase of construction projects. For specialist, green-field projects, Kentz Integrated Solutions (KIS) provide multi-discipline engineering services, including FEED (KENTZ, 2012). Tenaska Trailblazer Partners, LLC contracted with Fluor to complete a FEED study for the carbon dioxide capture portion of a project (Tenaska Trailblazer Partners, 2012). KBR Inc. has been awarded a contract by Saudi Aramco to furnish a FEED system at the Shaybah field. KBR provides FEED for the creation of the process design and layout, the development of equipment and material specifications, the preparation of bid packages, and the estimation of construction work with respect to several projects related to the Shaybah NGL Program facilities (KBR, 2011). A Korean research team supported by the Ministry of Land, Transport and Maritime Affairs of the Korean government developed an intelligent-program management information system (i-PgMIS). This system incorporates and integrates unit modules that can be used during the FEP phase: cost-duration management, contract management, risk management, performance management, green VE/LCC, change management, and conflict management. Emerson delivers a multi-disciplinary approach with FEED, in which the FEED document is the definitive technical and business project summary that includes all of the FEED deliverable documents to be used by the project team. The Emerson FEED system involves early design work performed after the conceptual business planning and prior to the detailed design (Emerson Process Management, LLLP, 2005). The Chiyoda FEED method, an efficient version (according to claims) that causes few changes during the EPC (Engineering, Procurement and Construction) phase, enhances project performance (Chiyoda Corporation, 2012). Bentley offers a FEED solution that provides the flexibility needed for construction projects while still ensuring interoperability among the multiple software products that are based on ISO 15926. The Bentley FEED tool has been helpful for major chemical companies such as Mitsubishi Chemical (Bentley, 2008). However, none of these models is comprehensive, and they all customarily focus on one or only a few aspects of FEP. While they have contributed significantly to the FEP phase and have satisfied their clients, they are entirely customer- and project-oriented, which means that some were employed only as a module for supporting a specific part of the FEP approach, with the remaining FEP being managed through either traditional approaches or existing partial models.

2.4 Construction Work Packaging

An appreciation of the research presented in this thesis requires a careful review of a number of important concepts, including work packaging. A work packaging system is an inclusive process flow that involves entire detailed packages. In turn, defining construction packages and packaging systems also necessitates clear terminology. Scholars and practitioners in a number of industry segments have defined work packages in a variety of ways.

As is clear from the literature, work packaging is not a new concept: a number of companies and scholars have used the term “work package” as a descriptor for a wide variety of planning objectives, defined based on the objectives of their specific project (Kim and Ibbs, 1995; Raz and Globerson, 1998; Choo et al., 1999; Gray and Hughes, 2001; Chan and Kumaraswamy, 2002; Sriprasert and Dawood, 2002; Machin et al., 2007; Wegener, 2008; Ibrahim et al., 2009; Sadeghi et al., 2010). However, regardless of any particular viewpoint, a work packaging system can be seen as providing a framework for productive and progressive construction.

The literature contains a number of definitions of construction work packages. In their report, *Work Packaging for Project Control*, a research team organized by the CII recommended breaking projects into manageable work packages. This team also defined a construction work package as “a well-defined scope of work that terminates in a deliverable product(s) or completion of a service. Each package may vary in size, but it must be a measurable and controllable unit of work to be performed.” To complete a work package, one or more tasks will be performed. Thus, a work package may encompass the work of more than one crew or staff” (CII, 1988). The Construction Owner's Association of Alberta (COAA) also proposed the following definitions for different types and levels of work packages, including the Construction Work Package (CWP), the Engineering Work Package (EWP), and the Field Installation Work Package (FIWP):

1. The Construction Work Package (CWP) is “an executable construction deliverable that defines in detail a specific scope of work and should include a budget and schedule that can be compared with actual performance. The scope of work is such that it does not overlap another CWP and can be used as a scoping document for Requests for Proposal and Contracts.”
2. The Engineering Work Package (EWP) is “an engineering deliverable that is used to develop CWPs and that defines a scope of work to support construction in the form of drawings,

procurement deliverables, specifications and vendor support and that is released on an agreed upon sequence consistent with the CWP schedule. The scope of work is typically by discipline and area.”

3. The Field Installation Work Package (FIWP) is “a detailed execution plan that ensures all elements necessary to complete the scope of the FIWP are organized and delivered before work is started to enable craft persons to perform quality work in a safe, effective and efficient manner. Generally the scope of work associated with the FIWP should be small enough that it could be completed by a single foremen team in a one or two week time frame” (COAA, 2007).

The COAA model diverges from the CII model in that it does not recommend a hard connection to project controls.

The research presented in this thesis deals with issues related to the management of the construction supply chain using work packages, a topic with respect to which, despite some pioneering research, significant gaps exist (Jaselskis and Ashley, 1991; Choo et al., 1999; Vrijhoef, 2000; Miller et al., 2000; Raz and Globerson, 1998; Cox et al., 2006). This research concentrates on industrial construction, which involves projects such as power plants, refineries, and process facilities. This sector is characterized by a substantial concentration of participants, by owners who build often, by the involvement of trades such as pipefitters and millwrights, and by a high level of engineering and project management sophistication. Much of what is learned in this area can be generalized to include other construction sectors.

2.4.1 Work Breakdown Structure

An important approach that should be addressed in the development of construction work packages is the work breakdown structure (WBS). The WBS evolves through the process of breaking down a construction project into individual components arranged in a hierarchical structure. In other words, it is the process of taking the project apart to the level of the construction value package. The project schedule, on the other hand, lists all of the tasks required in order to complete the deliverables. As one authority says about the result of this process, “The WBS provides an opportunity for all key stakeholders on a project to view the project in the same manner, to speak a common project language for the first time” (Fleming and Koppleman, 1996). Determining the appropriate level of detail is

critical, and the project team must avoid both defining tasks too specifically (at too high a level of detail) and defining too large a task.

The breakdown of the work can be illustrated as a hierarchical structure. Figure 2-3 provides a general illustration of how a large project can be broken down into subprojects and then developed into value packages. Each piece of the puzzle shown in the figure represents a specific value unit that then becomes part of a value package.

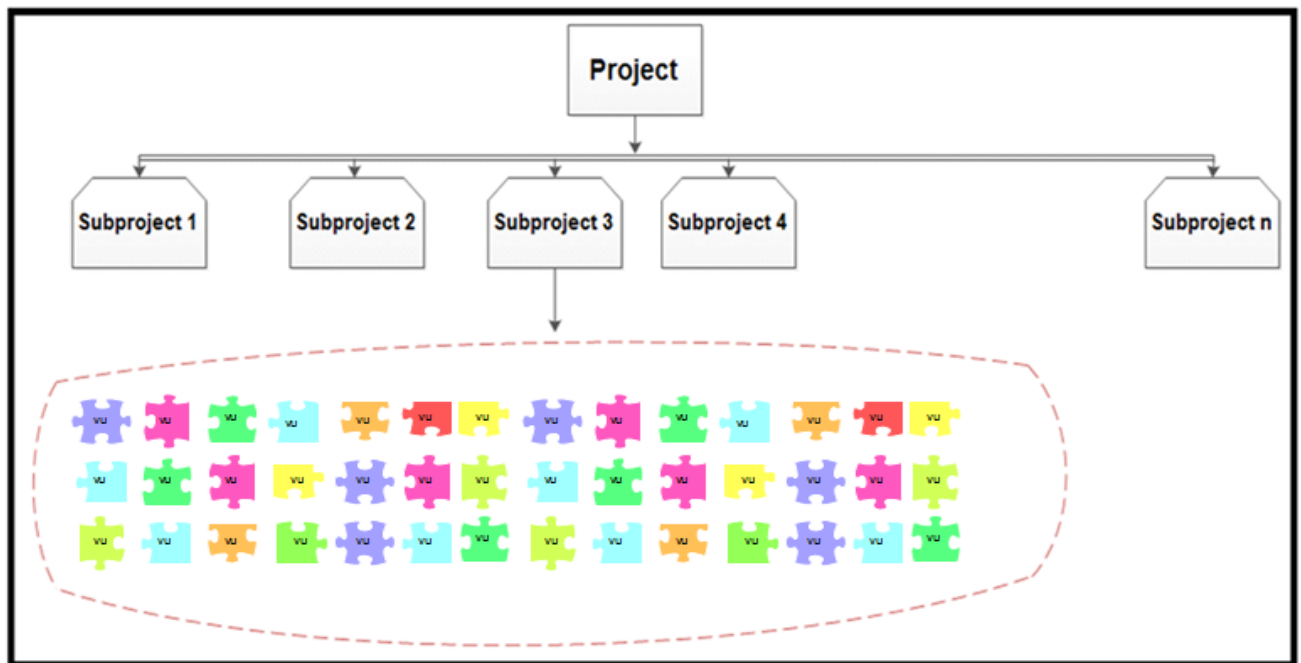


Figure 2-3: Work Breakdown Structure for the Value Packaging Concept

The Project Management Institute advises that WBS development should progress in increasing detail until a level is reached that makes available the insight and vision required for effective project management (PMI, 2002). Since one value unit includes a variety of types of work items, the number of value units thus rapidly increases as a WBS is subdivided into one or two additional levels downward. Care must therefore be taken to achieve an appropriate level of detail in an organized manner. The level of detail in a WBS is related to the class of the project and its cost, duration, and complexity. It should be noted that each individual construction company with many years of experience and multiple experts might have its own specific structure for defining the WBS.

Hendrickson defines the principles behind difference approaches (Hendrickson 2000). The WBS must therefore be flexible enough to provide suitable features for a variety of users.

2.5 Materials Management

Construction materials management can best be defined as “the planning and controlling of all activities necessary for ensuring and confirming that the correct and accurate quantity and quality of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed” (“Business Roundtable”, 1982; CII, 1986). A review of existing construction materials management systems reveals that the current practices for materials management of sites or fab-shops needs improvement. Semi-integrated and ineffective construction materials management systems are evident in a number of projects and generate considerable wasted time and money (Thomas, 2005). In typical construction projects, the cost of materials constitutes 50 % to 60 % of the total cost of the project (Stukhart et al., 1985; CII, 1988; Akintoye, 1995; Wong and Norman, 1997; Andraw, 1998; Ibn-Homaid, 2002; Caldas, 2004) and their management affects 80 % of the project schedule (Kerridge, 1987). An integrated, real-time materials management system for construction projects is therefore strongly needed. Materials management systems are the subject of numerous requests for the development of new applications, and the enhancement or amendment of existing ones that, as important and complex functions of a project, require substantial improvement (Ibn-Homaid, 2000).

A materials management system should be a well-integrated tool that can perform a variety of functions related to inventory control, the bill of materials (BOM), the supplier history, item inquiry, pricing services, and the purchasing process. The last item is a key element that usually involves tasks such as selecting and awarding suppliers, analyzing proposals, delivering purchases, inspecting goods supplied, and maintaining a variety of purchasing records (Dobler, 1996).

The addition of an integrated and seamless construction materials management system should be carried out over a reasonable period and during the Front End Planning (FEP) phase (Chapman et al., 1990). Materials management is also affected by the previously mentioned “temporary multi-organization” (Koskela, 1997), or domination by uniquely defined and executed projects (Vrijhoef and Koskela, 2000; Gann and Salter, 2000; Cheng and Li, 2001), that is characteristic of the construction industry. As with other construction systems, a construction materials management

system should therefore be flexible enough to meet the materials management requirements for a wide variety of projects.

The introduction of new systems in the construction industry has not kept pace with the progress experienced in other industries (Pries and Janszen, 1995; Lin and Chen, 2004). However, construction materials management is a multi-disciplinary field that is appropriate for and can build on the cooperation between construction processes and some aspects of the manufacturing industry that entail a variety of activities for the large-scale conversion of raw materials into finished products.

Because EPCs (Engineering, Procurement and Construction) and construction companies cannot perform all required project tasks on-site, construction managers (experts) have tended to use staged-fabrication technologies whereby operations traditionally performed on-site have been moved to a manufacturing environment. Staged fabrication represents one segment of the broad spectrum of contemporary innovative techniques that are appearing in the construction industry. It offers an opportunity to overcome some of the challenges associated with a project, such as the absence of site inventories, demanding schedules, lack of local skilled labour, permit requirements, and adverse site conditions. These technologies can be helpful in the production of a wide variety of buildings and the construction of an equally wide variety of industrial projects, such as nuclear power plants and pipelines (Canadian Encyclopedia, 2012).

An advanced construction supply nexus management model cannot improve the materials management processes for EPCs and construction companies without integrating off-site (staged-fabrication) and on-site systems. To provide an understanding of the off-site segment of the system, the staged-fabrication method is addressed in the next section, followed by a discussion of site materials management.

2.5.1 Staged Fabrication (Off-Site)

The application of staged-fabrication principles to construction supply nexus management is beginning to show benefits with respect to quality, time, and cost savings. In a traditional construction supply chain model, most fabrication activities and tasks occur on-site. Staged fabrication is a method of working with contractors so that products such as pipe spools and precast concrete elements are delivered more quickly to a construction site.

This trend toward staged fabrication has the effect of adding value earlier in the supply chain (Sacks et al., 2004). The process is based on a concept that can be utilized in construction materials

management and that includes consideration of the particular specifications for each class of project. An understanding of staged fabrication requires clarification of some of the terminology and concepts: preassembly, modularization, and prefabrication. Prefabrication is defined as the transfer of a stage of construction activities from the field to an off-site production facility (Tatum, 1986). Implementation of prefabrication requires the collaboration of clients, developers, designers, contractors, manufacturers, suppliers, government agencies, advisors, and researchers. Prefabrication, preassembly, and modularization systems have been addressed by CII in an excellent study conducted in 1998. This method can help improve site safety because it results in a cleaner and tidier site environment, it can enhance quality, and it can reduce the total amount of work that must be redone at the construction site. With respect to transportation considerations, prefabricated elements have a higher added value than bulk materials. A variety of prefabricated building components are commonly used in the construction industry, including the following (Tam et al., 2007):

1. Semi-prefabrication comprises non-structural prefabrication applications such as facades, curtain walls, lost-form systems, and dry-wall systems.
2. Comprehensive prefabrication consists of structural prefabrication applications, such as staircases, slabs, columns, and beams. Most comprehensive prefabrication is pre-finished at a fabrication site prior to installation.
3. Modular, or volumetric, building technology is the ideal solution for most modern construction projects and is fully finished off-site as a “one-stop” system. Pipe modules in industrial projects are a typical example of modular construction.

The Center for Construction Industry Studies report from the University of Texas at Austin (Haas et al., 2000) resulted from a survey of 29 managers from across the United States. Based on their responses, it was estimated that prefabrication and preassembly increased by approximately 86 % from 1984 to 1999. The implications of modularization for the management of the construction supply network are receiving increasing attention in the literature related to purchasing and supply management (Voordijk et al., 2006). The initial implementation of prefabrication was not viewed positively; however, its use has been increasing during recent decades, and it is now a vital component of most capital projects, particularly in the industrial sector.

The application of off-site techniques has already resulted in a profound change in the development of the construction industry worldwide. The value of such techniques includes the possibility of

enhanced quality control, improved design details, compressed schedules, and reduced reliance on site labour. These benefits come at an increased cost for some projects, but the additional cost could decrease over time, as the construction industry becomes familiar with the prefabrication process (Yeung et al., 2003). The materials to be delivered are, in fact, manufactured products with value added by a separate workforce, and the percentage of the total costs represented by the amount required for direct labour and materials for a project may thus change if additional prefabricated units are incorporated into the construction project (Hendrickson and Tung, 1998).

2.5.2 On-Site Materials Management

Not only can productivity be increased if an efficient materials management system is put in place at a construction project, but other benefits accrue as well, including the avoidance of procurement delays, a reduction in the number of man-hours needed for materials management, and a decrease in the costs associated with delays and wasted materials. Thomas and Sanvido (1987) have investigated the amount by which productivity is reduced because of inefficient materials management. They considered a number of materials management factors that could potentially affect productivity on a construction site: disruptions, work content, environmental issues, constructability, construction methods, and management aspects.

It should be noted that an effective integrated materials management system must be fully supported by project management, site management, and craft personnel, while its success and cost-effective operation depend on the presence of experienced personnel capable of handling multiple job responsibilities in the head office or in the field. The home office is the source of a significant portion of the work related to site materials: the identification, requisitioning, purchasing, and expediting of all materials. In other words, site materials management extends beyond the activities of receiving, storing, and issuing materials (CII, 1999). The site activities described in this thesis are therefore well planned and executed; however, they must also be an orderly and logical continuation of an overall materials plan that includes the home office component.

Elzarka and Bell (1995) stated that on-site materials management systems must be integrated with the computer systems that are used for design and scheduling. They developed an object-oriented methodology (OOM) data structure for a materials management system. The attributes of materials management systems that contribute to the success of a project were identified by Bell and Stukhart (1986). They associated their findings related to the attributes of materials management systems for mega and complex industrial construction projects with the control of the functions related to quantity

takeoff, vendor evaluation, purchasing, expediting, receiving, warehousing, and distribution. Their work showed that lack of proper management of these functions leads to shortages and surpluses of materials and to cash flow problems. Robust planning and communication were also examined as vital components of an effective materials management system. In another study, Bell and Stukhart (1987) presented a quantification of the costs and benefits of materials management systems. They also quantified the savings in the areas of improved labour productivity, reduced surpluses of bulk materials, fewer manpower requirements for materials management, and enhanced cash flow. Surpluses of bulk materials were reduced from a range of 5 % to 10 % of the amount purchased to about 1 % to 3 % of the amount purchased. This study also showed that an efficient materials management system can reduce the man-hours needed for materials management: in the absence of a materials management system, craft foremen spend up to 20 % of their time searching for materials and another 10 % tracking purchase orders (POs) and expediting delivery.

Strong evidence shows that an optimized materials control system on-site can ensure the availability of sufficient quantities of materials and equipment for construction needs and the minimization of surpluses at the end of the project (CII, 1999). The *CII Materials Management Handbook* (CII, 1999) lists elements that can cause shortages of materials: lost or damaged materials, materials required but not purchased, materials purchased but not received, errors in material takeoff, variances in additional material requirements, and materials that are issued to crafts and are not used or installed. With the cost of materials representing 50 % or more of the total construction cost, it should be evident that efficient materials management is crucial and that a materials management plan and the commitment to carry out that plan are critical for the success of construction projects.

The foregoing review shows that a successful construction supply nexus model must integrate both the on-site and off-site aspects of construction materials management. It should be noted that the complex system presented in this thesis has been developed for the use of EPCs. While some construction companies may use in-house or commercial systems to meet their day-to-day materials management needs based on their specific requirements, our research shows that no model with an appropriate degree of integration has yet been developed or suggested in the literature. The following sections include a discussion of the important concepts and characteristics related to construction materials management that were used extensively in the development of the model presented in this thesis.

2.5.3 Concepts and Characteristics of Successful Materials Management Systems

This section provides a review of the characteristics and concepts related to materials management systems based on the relevant published literature. These concepts formed a significant basis for the development of the integrated construction materials management system as an element of the construction supply nexus model (Chapter 6).

Planning and Control

Enormous cost overruns can be caused by shortages of materials resulting from lack of proper materials planning and control. Improper material planning and control result in: the absence of adequate statistics related to the availability of the materials, a shortage of funds for procurement (budgeting), inadequate transportation capacities, excessively long average waiting times and vagueness about the delivery of the materials ordered, and uncertainty about the availability of some materials (Okpala, 1988). To address these deficiencies, among the goals of materials management are the provision of improved control of materials, the ability to forecast delays, enhanced reliability of information, and an increased ability to adjust to unexpected conditions (CII, 1999). Materials planning integrates and combines the functions of vendor enquiry and evaluation, project planning (CII, 1988), purchasing, material takeoff, transportation, field materials control, and warehousing. The large investment in construction materials provides an opportunity for the development of a more efficient system that can reduce surpluses, increase productivity, provide cash flow savings, enable quantity purchasing, and minimize costs and the impact of changes (Randolph et al., 1989).

As mentioned, two of the most important elements of any effective construction materials management system are planning and communications (CII, 1986). All of the materials-related responsibilities of the engineer, owner, contractor, and subcontractors must be clearly defined early in the project. These responsibilities are often delineated in such a way that the owner/engineer is in charge of the engineered equipment (major items that are given unique importance within the project design), and the construction manager, contractor, and/or subcontractor are in charge of the bulk materials.

Engineered materials and equipment are the costliest, most visible, and most critical aspects of a project and usually drive the project schedule. Planning for bulk materials is more complex because they usually involve large quantities and because the evolution of the design results in the continual updating of bulk requirements. No exact quantity is therefore available for bulk materials until the job

is completed. It is important that the expediting process include sufficient information to enable alternative plans to be evaluated when problems arise.

The schedule of the entire materials program is critical if project deadlines are to be met. Materials schedules are as essential as those for engineering and construction, with their scope covering all phases of the project, from the definition and approval of the requirements to purchasing, transportation, vendor lead time, and site management (CII, 1986). Transportation planning should include consideration of cost, safety, timely delivery, and hazardous materials content. During the project planning phase, the owner (main contractor) must define for the contractor of the project any constraints, such as laydown areas and/or restricted areas, that may affect the cost and scope of the materials management functions. To aid in the coordination and execution of all of these functions, the integration of software systems is usually required. A materials specification and coding system must first be established for handling bulk materials. To establish accurately from the design which materials are required, a materials takeoff (MTO) is created. The MTO provides a base list of all the bulk and engineered items required for the project. However, the creation of composite items requires that they be quantified and arranged based on their relationships, so a Bill of Material (BOM) must therefore be created from the MTO in order to define the requirements with respect to project materials.

Labor Productivity and Cost

A CII study (1986) on productivity showed that the unavailability of materials on construction job sites increases craft labor productivity by up to 6 %, and at the same time, the execution of computerized materials management systems provides an additional gain of between 4 % and 6 % for construction megaprojects. Assaf and Al-Hejji (2006) demonstrated the interconnection of labour-related causes and issues with feasible overrun times for Saudi Arabian construction projects. Based on their observations, the unavailability of materials and resources negatively affected craft labour productivity by increasing the related amount of time spent on craft labour activities. According to a study by O'Brien (1989), the time spent by electrical workers on materials handling and preparation is almost 42 %, while just 32 % of their working time is dedicated to productive activities. Research conducted by Borchering and Sebastian (1980) showed that craft labour is idle 27.7 % of the time because of the unavailability of the required quantity or quality of materials, and costly labour delays then result due to an inefficient materials management system (Bell and Stukhart, 1986). An advanced construction materials management system can therefore clearly improve labour

productivity and should be considered during the development phase of any construction management system.

The costs associated with developing and implementing materials management systems are both substantial and debatable. Growing evidence shows that an efficient materials management system can ensure that the quantities of materials available are sufficient for construction needs and can minimize surpluses at the end of the project, thus leading to huge cost savings (CII, 1999). Such a system creates an interface between the most important contractors and the suppliers, which can decrease the average cost of materials by up to 10 % (Asplund and Danielson, 1991; Jarnbring, 1994), and the appropriate supervision of the flow of materials may also play a substantial role in enhancing the effectiveness of a contractor (Polat, 2005). The research conducted by Pettang (1997) describes an approach aimed at helping project decision makers and other participants, such as the client, builders, property developers, subcontractors, and the municipality, with the challenging task involved in forecasting the cost of materials for urban house projects.

The report provided by Forde (1993) presents a detailed study of the cost management of both concrete and steel materials, and provides details of materials management work in countries that include USA, Canada, France, Japan, Norway, and Sweden. Manavazhia and Adhikarib (2002) linked materials-related factors to probable cost overruns in construction projects in Nepal.

All of the reports mentioned, along with other related research, demonstrate that the absence of materials on-site is one of the most commonly experienced causes of delays in construction projects and a significant driver of overrun costs (Arditi et al., 1985; Abdul-Rahman and Alidrisyi, 1994; Ibn-Homaid, 2002). In addition to these studies, the procurement guidelines for both the US and Canadian armed forces also emphasize the choice of cost-effective construction materials (Reiche, 1970; Gansler, 1974).

Waste of Materials

The minimization of waste with respect to construction materials is a significant issue in many countries. Experts recommend that when they are preparing designs, designers employ a system that has less potential to produce site waste (Ekanayake, 2004). On-site materials management thus should emphasize a waste management plan for each construction site (Coventry et al., 1999). A comprehensive materials management system has the potential to address all materials management challenges associated with waste management except human-oriented issues (labor) and

environmental aspects. Construction experts have established a set of waste-prevention strategies for construction projects. These strategies involve primarily the effective coordination of materials management: the well-organized purchase and proficient ordering of materials, an effective delivery schedule, effectual storage, the maximization of reuse, the prevention of rework, etc. (Fishbein, 1998). The implementation of an integrated materials management system would provide a valuable opportunity to reduce the amount of materials wasted and to increase the recovery of those that would be otherwise be wasted.

Bill of Materials

A bill of materials (BOM) is one of the principal elements of any materials management system. Several significant pioneering research studies have been conducted with respect to how BOMs are prepared and used. In general, a BOM is a document that specifies how a product is built up from its individual components (Hegge and Wortman, 1991), which may, in turn, have their own BOMs. A BOM system constitutes a major component of the input for the planning and control of manufactured products; it contains a hierarchically arranged network of product relationships, in which the top tier indicates a product that is not a component of any other. Products that do not have a BOM are called primary products. Between the primary products and the top products is a category termed subassemblies (Chung and Fischer, 1994). In construction, the concept of subassemblies is related to staged-fabrication.

Because it contains the parts lists for the subassembly or assembly products, the BOM has been used for product design, procurement, manufacturing, production scheduling, and maintenance. Outside of construction, a BOM is commonly used for product life cycle management and for enterprise information systems as a means of communication during product development. Hegge and Wortman (1991) proposed a generic BOM that would describe all variants of all components and that would make it possible to construct a specific BOM for a specific product variant. Similar components could be grouped as one generic component, so that each component description would exist only once in the generic structure, but the variant set of a component would be described independently. Olsen et al. (1997) created a generic BOM system that prompts the user to select the specifications for the generation of the required variant. Their new BOM also applies any constraints related to specific variations of a product and deals with the issue of a large number of similar BOM structures based on a customer-oriented philosophy.

Jiao et al. (2000) designed a generic bill-of-materials-and-operation (BOMO) by unifying the BOM and then routing data into a single set in order to synchronize multiple perspectives related to a variety of factors, such as customer ordering, product engineering, and operations planning. The reported merits of the generic BOMO for integrated product and production data management are related to order processing, engineering change control, production job planning, cost accounting, and integrated materials and capacity planning.

To address issues such as the failure of previous systems to provide complete parts data for the department of procurement and sales, Zhang et al. (2011) designed an auto-parts data management system based on the BOM. Lee et al. (2012) integrated the BOM with the design of ship-outfitting equipment and showed that the architecture of a BOM can be used to define the relationships among parts, assemblies, and an overall view of a BOM that evolves with ship design.

The concept of BOM management plays a critical role in the development of the Integrated Construction Material Management (ICMM) system of the research presented in this thesis. BOM management system as well as its optimization and automation are further discussed in Chapter 6 of this thesis.

2.6 Web-Based Project Management and Project Interfaces

Integrating all of the elements and systems of a construction project becomes possible with the use of web-based project governance. Sites, headquarters, suppliers, construction managers, and stakeholders already employ a variety of communication methods such as fax, email, and telephone, so a construction supply nexus model should incorporate web facilities to enhance prompt communication and to improve the integration of the different systems in the model. As presented in this section, the literature related to the use of web technology was therefore reviewed, and the required interfaces were investigated.

Biggs (1997) categorizes poor communication as the root cause of most project failures and indicates that even early web-based solutions could reduce the frequency of people-related difficulties and communication problems that lead to project failures. The web and associated technologies can be used for the management of construction projects, a concept widely acknowledged by practitioners and often referred to as a web-based project management system (WPMS). A WPMS enhances construction project documentation and control and can reengineer the way in which a construction project team manages work processes. These systems have also been given other names: a document

management system (DMS), a project extranet, a project web, a project bank, a project-specific website, a document pool, a project information management system (PIMS), and a virtual project. A WPMS can be defined as an electronic project management system conducted through an extranet, which is a private network that transmits information through internet protocols, network connectivity, and possibly the public telecommunication system. A WPMS is accessible only by a project team, but team members can be located in different organizations (Nitithamyong and Skibniewski, 2004). Such a system inherently establishes a centralized, accessible, and reliable means of transmitting and storing project information (O'Brien, 2000).

Web-based project management technologies can be a gateway for the exchange of construction project information and for the elimination of difficulties resulting from different geographic locations. Using this type of system, project managers can also manage the exchange of documents between members of the project team. During project design and implementation, each team member must receive the correct documents at the correct time, such as the latest version of drawings, specifications, and requirements. Using web-based project software during this stage can provide the following (Alshawi and Ingirige, 2003) benefits:

1. Reduction in the risk of errors in and the necessity for the rework of processes by ensuring that everyone on the project team is working with the maximum number of documents
2. Time savings in the query and approval process by enabling the design engineers to mark up and comment on drawings and other documents online
3. Elimination of the risk of losing important files because of the back-up and maintenance of all current and past versions in one central location
4. The ability to permit team members to raise and respond to queries in a structured way, thereby improving team communication
5. Facilitation of an audit trail through the maintenance of a complete log of all communications for tracking purposes
6. The ability to allow clients and other participants to view the as-built project through the incorporation of virtual models that can denote the status of a project at any point in time
7. Provision of an environment through which diverse participants can collaborate online

This review shows that the development of an advanced construction supply nexus model requires the use of web facilities in order to ensure the promptness and accuracy of communications through the definition and clarification of all interfaces and channels of information. In other words, the central relationships in the modeling of construction processes are the associations between the processes and the tools and systems through which they operate. In a construction supply nexus model, the nexus represents the linking of the independent/dependent parties for a variety of purposes. This linking, or integration, of information activities can be defined as the exchange of information between multiple nodes for the efficient creation and use of construction process details. It should be noted that large reengineering activities that help integrate information processes should take into account any effects the project management process has on the organization of the overall process (Bjork, 2002).

No standard “one size fits all” can be created for a construction project interface toolbox. For several small projects, the project team can manage effectively with a tool as simple as an Excel spreadsheet, coupled with frequent face-to-face contact and extensive meeting minutes that include precise action items. All major capital projects involve complex interface interdependencies among diverse contracting parties, which create challenges with respect to on-time and on-budget project performance. Without consistent control over these interfaces, project risk escalates and the potential for project delays, cost overruns, and other negative outcomes increases. Collaborative work processes and search capabilities can empower project stakeholders by providing the information they need in order to complete their required interface activities on time and to mitigate risk throughout the entire life cycle of a project. Several models and software applications have been developed for this purpose. For example, the industry partner of the research presented in this thesis, Coreworx Inc., has developed an interface management system that reduces the cost of interface-related problems in complex, mega-capital projects. This study therefore included consideration of the concept of interface management, which is included in the developed model. The Coreworx interface management solution is used as a means of facilitating the interfaces among parties with respect to roles and responsibilities, required dates for providing interface information, and identification of critical interfaces early in a project. The interfaces may be between internal divisions of a single company or between companies that have no connection other than through the work coordinated by the software. In general, interfaces can be categorized as physical, contractual, or organizational (Pavitt and Gibb, 2003):

1. Physical interfaces are the actual, physical connections between two or more building elements or components. In any construction project, physical interfaces are inevitable and occur either between two elements of a value unit (Appendix A) or between different value units; however, their number and complexity are dependent on the detailed building design.
2. Contractual interfaces occur during the development of value packages (Appendix A), which create interfaces between the value units normally associated with specialist contractors. Contractual interfaces between value packages must be agreed upon before the construction phase begins and should be managed throughout the project.
3. Organizational interfaces represent the interactions among the various parties involved in a construction project and can therefore include many different companies and subdivisions of companies. Efficient management of the relationships among these parties is essential for the successful completion of a project (Gibb, 1995).

Based on the above definitions, interface management as a whole can thus be defined as the management of communication, coordination, and responsibility across a common boundary between two interdependent value unit providers (contractors, suppliers, or vendors), value units, or value packages. It therefore affects all relationships among the stakeholders of a project.

In recent years, Electronic Product and Process Management System (EPPMS) has emerged as the new generation of web-based project management systems in the construction industry. An EPPMS links project stakeholders over a range of distances via the internet and system servers. While related systems include building information modeling (BIM), integrated construction project management systems, enterprise resource planning (ERP) systems, and generic electronic document management systems (EDMS), an EPPMS is unique. It differs from a generic EDMS, because it directly expresses the project delivery mechanism and processes. In the construction industry, EPPMS solutions are used to facilitate the execution and knowledge management on mega construction projects. Coreworx Inc. is a pioneer EPPMS provider in the mega capital project domain, and the sponsor and a main supporter of the research presented in this thesis. The functionalities of Coreworx EPPMS, including process workflows, web-based collaboration mechanisms, and document and information management systems, were exploited in the development of the various components of this research. The developed model in this research requires some services which can be provided by Coreworx EPPMS. However, several construction software companies have provided similar products.

2.7 Summary

This chapter has summarized the relevant research with respect to the construction front end planning, work packaging, material management, and web-based project management. The material was arranged thematically so that it corresponds to the steps involved in exploiting the developed model, as presented in the following chapters of this thesis. The review of the literature demonstrated that there is a strong need to improve the integration between different components of construction materials management. Specifically, the Bill of Materials (BOM) optimization and automation were identified as a tool that could significantly improve the processes related to the construction supply chain management. Finally, a review of the web-based project management tools indicated a need for an efficient, reliable and scalable integration mechanism for providing the required communication among all parties involved in the developed supply chain management model. The next chapter presents the knowledge gaps evident from the literature as well as the research vision, approach, and structure.

Chapter 3

Research Vision

This chapter presents the vision of this research with respect to the development of the Advanced Construction Supply Nexus Model (ACSNM) based on the needs and knowledge gaps identified through the literature review. The elements of the developed ACSNM are also addressed: the Front-End Planning Tool (FEPT), the Construction Value Package System (CVPS), the Integrated Construction Material Management (ICMM) System, and the ACSNM database. The approach taken during this study is also explained.

3.1 Knowledge Gaps Identified in the Literature Review

The review of the literature indicates that when construction on a megaproject nears its peak level of activities, several hundred highly paid skilled craft workers are typically on-site, as well as a significant number of subcontractors. The project manager and subcontractors are related through complex contractual agreements and management structures that must be established quickly, must operate smoothly throughout the construction phase, and must then be dismantled when the project is completed. Laydown yards and project warehouses contain thousands of engineered materials that must be managed, including valves, pipe spools, and instrumentation. Pending their installation, key engineered components such as turbines even require regular on-site maintenance, such as regular rotations and lubrication.

For nuclear projects and most mega construction projects, the level of complexity is multiplied by the requirements related to positive materials verification throughout the entire process of their fabrication and movement through the supply network. Then, once the construction phase has ended and start-up is complete, the documentation of the project in the form of tens of thousands of documents, electronic files, as-built models, and specifications must be transferred smoothly to the owners and operator. Such complexity creates a tremendous challenge with respect to information control related to the management of the supply nexus process.

Previous studies have shown that addressing the individual challenges connected with the implementation of supply nexus materials management is becoming increasingly feasible due to emerging technical and technological advances, which have motivated a large number of research initiatives in this field. However, the lack of integration between project-level systems has limited the

data exchange capabilities between these systems, requiring a number of highly labour-intensive processes. These manual processes not only reduce the quality and consistency of the data but also prohibit any sort of real-time project monitoring or reporting capabilities.

Therefore, despite the success of one-off initiatives that use separate and often project-specific systems to address individual challenges in the construction industry, a strong demand now exists for a robust supply nexus management system that can provide a framework for integrating these islands of information and workflow processes.

Finally, the growing size and complexity of mega construction projects in recent years have underlined the fact that poor definition and ineffective management of project interfaces lead to delays, budget overruns, increased project risk, and miscommunications and misalignments among stakeholders. An effective supply nexus management system should therefore be able to support a structured approach to handling and managing megaproject interfaces, beginning with front-end planning (FEP) and progressing through construction to commissioning (Appendix K). The supply nexus management system should also be capable of identifying the interfaces very early in the life cycle of a megaproject, when the opportunity to decrease project risk is greatest.

3.2 Model Development

The importance of industrial facilities (e.g., power plants, refineries, factories, and mines) in economic prosperity and the quality of life is well accepted. Effective planning, design, and construction of these facilities require comprehensive construction supply nexus management. However, the project supply nexus management of the construction of individual facilities is particularly complex and challenging. A typical facility may incorporate tens of thousands of engineered components, systems and subsystems, all of which must be designed in a multi-party, collaborative environment. Components are procured and managed by means of a supply network that extends from local fabricators and vendors to global suppliers. The development of the Advanced Construction Supply Nexus Model (ACSNM) presented in this thesis was therefore undertaken with the goals of improving schedules, reducing costs, and enhancing the supply nexus process through the project life cycle. The following chapters demonstrate the impact of the model on construction supply chain processes and, ultimately, on construction project performance. The four elements of the ACSNM are depicted in Figure 3-1: a front-end planning tool (FEPT), a construction value package

system (CVPS), an integrated construction materials management (ICMM) system, and the ACSNM database.

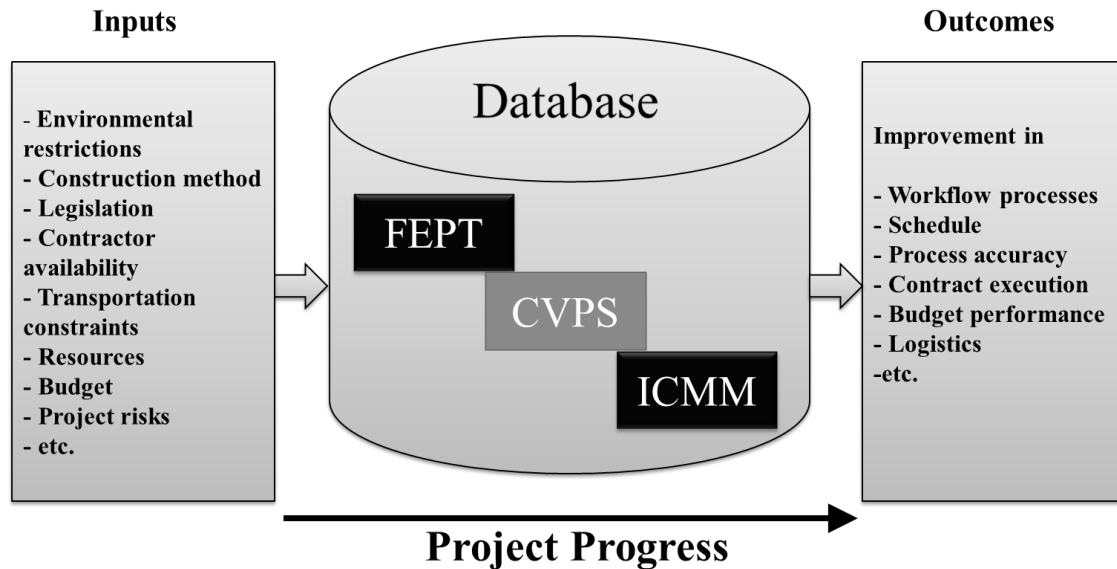


Figure 3-1: Elements of ACSNM

In contrast to existing construction supply chain management models, the emphasis in the ACSNM is on its integrated nexus structure. Figure 3-1 shows a simplified illustration of ACSNM, in which many interrelated systems and processes are embedded. These integrated systems interface with one another through the ACSNM database.

The ACSNM can be used to formalize procurement processes, to integrate design and materials management processes, and to enhance the visibility of the supply nexus for construction projects. Formalizing procurement processes helps assure their quality and execution by enforcing consistency, repeatability, responsibility, and accountability and also provides a framework for management processes. As presented in this thesis, ACSNM facilitates this formalization for several processes through its process maps, workflow diagrams, RASCI charts, and visualization tools.

Building on the formalization of the processes, the activities and communications of the stakeholders can be integrated with the design, procurement, and materials management processes. The ACSNM provides formalized process channels via the Coreworx EPPMS for managing the stakeholder exchange of electronic products and design documents. The resulting streamlined communications, reduced data re-entry, and accelerated response times add significant value to the supply chain

management process. The ACSNM also facilitates enhanced visibility because it manages for all project stakeholders the communication of the status of the design, fabrication, finishing, and transportation through the sharing of design documents, document revisions, shipping manifests, invoices, and other project management documents. Figure 3.1 shows the major forms of input to the model: project budget, resources, governmental legislation, contractor availability, and transportation constraints. The input of the model is used in Front End Planning (FEP) facilitated by the FEPT, the first element of the model.

The FEPT was developed through collaboration with the industry partner as part of a larger research project whose goal was the application of software technology in order to address the unique characteristics of the planning process and to provide the construction industry with an adequate process management tool to support FEP. A software tool was developed and designated an FEPT, which manages the execution, monitoring, and control of the work activities associated with planning in order to ensure that all deliverables are completed efficiently. The FEPT is a useful tool that has been developed in this research with consideration of all aspects of FEP in order to provide a widely applicable and comprehensive electronic process management system for project planning. The integration of the FEPT with other model components is important and enables construction value packages to be developed once all of the FEP steps are completed.

The construction value packaging system (CVPS) is a core contribution of this research. The development of the ACSNM required the definition of a new concept: the value unit. Value packages are considered to be comprised of these value units, whose scope includes value-added work defined by the type of activity; its stage in the value chain; and other elements, such as drawings and specifications. Through the application of the value packaging concept and its associated new technologies and methods, the CVPS can improve the performance of the construction supply chain process.

Once construction value packages have been prepared, iterative improvements should occur during the next phase. This step is dependent on the early collaboration of the project management team, the contractors, and the other stakeholders in the project, because the knowledge provided by specialists and experts and the information stored in the historical database are highly useful during this stage. It should be noted that each construction package may contain more than one bill of materials (BOM); however, assigning only one BOM to a construction package is more desirable and manageable.

One of the important elements of this model is an integrated construction materials management (ICMM) system. The ICMM was developed with the goal of overcoming the manual and inefficient nature of the order process by enabling the identification of the appropriate BOM whose total cost and primary product availability results in the procurement of the most cost-effective alternative for a particular product. The ICMM system is tailored for the internal parties related to a project, such as the site management team, warehouses, the financial department, and the purchasing department, as well as for external parties, such as suppliers, fabricators, and transportation companies.

The ICMM is presented as part of a construction value packaging approach for the project procurement phase. Its potential for improving construction supply management processes can lead to enhanced project performance, but it must be integrated with the other elements of the model. The ICMM is based on consideration of the majority of activities associated with the procurement of materials: the processing and administration related to purchase requisitions, purchase orders, internal supply requests, materials contracts, the expediting of materials, shipping, and costs. The ICMM system addresses both construction and manufacturing processes. To provide an understanding of the manufacturing segment of the ICMM system, the staged-fabrication method (off-site) is also discussed in this thesis, followed by a discussion of on-site materials management and the design, implementation, and integration of the ICMM system.

The fourth element of the model presented in this study, the ACSNM database, has been developed to be compatible with every other component of the model. It is workflow driven and helps to integrate all of the systems in the model.

The ACSNM output typically fits with the model's structure and takes into account the size, location, and schedule of the project as well as any cash flow constraints, the owner's philosophy, and the overall project strategies, all of which are discussed in the following chapters. Some of information output by the model is shown in Figure 3.1.

For models related to the construction industry, validation can be defined as a process of judging how well a model works for managing construction projects with respect to the structure and anticipated outcomes. It must be determined whether the model implements any assumptions accurately and whether the assumptions are reasonable with respect to a real system. As a result, the model may have different levels of validity for different parts of the system across the full spectrum of system behaviour. Analysis based on real rather than theoretical case studies is the most reliable and preferred manner of validating such a model. In practice, however, this method can be difficult to

employ because the model is new and evolving. Assumptions, input values, output values, workloads, configurations, and system behaviour should all be considered when the expected performance of the model is articulated.

For the purposes of this research, a validation-by-parts strategy was adopted. The FEPT validation involved data from three projects, supplied through our research partner, Coreworx Inc, who approved the use of this data conditional on the removal of any information identifying the projects and confirmation that their customers were comfortable with this approach.

Two Aecon megaprojects were also used in order to validate the CVPS and its algorithms with respect to the developed work processes and within the context of the ACSNM. The validation clearly demonstrated the advantages of using the CVPS and also pointed out its limitations (Chapter 5). Because it provided assurance of the efficacy of the CVPS and its algorithms and functioned as a guideline for amendments, the validation added value to this study. Other benefits included the acquisition of knowledge and experience with the use of best practice techniques and processes; the identification of any functional errors; the evaluation of the impact of the model limitations; and finally, the investigation of potential improvements to the model.

3.3 Research Structure

The most significant contribution of the research presented in this thesis is the development of a comprehensive model for the improvement of construction supply nexus management processes. Figure 3.1 addresses the four important elements of the ACSNM: the FEPT, the CVPS, the ICMM, and the ACSNM database. The next four chapters present the FEPT used for managing the FEP phase of construction projects; the CVPS and its algorithms; the ICMM and its BOM optimization algorithms; and the integration component of the model, the ACSNM database, which provides the platform for combining the data from all of the other components and for interfacing with other stakeholders and systems that may be involved in a construction project.

Chapter 4

Front-End Planning Tool

This chapter discusses the front-end planning (FEP) phase of a construction megaproject and its requirements with respect to an Advanced Construction Supply Nexus Model (ACSNM). A front-end planning tool (FEPT) is then introduced as one of key elements of the ACSNM for managing and meeting the requirements of the FEP phase. Figure 4-1 shows the ACSNM inputs, its core elements including FEPT, Construction Value Packaging System (CVPS), and Integrated Construction Material Management (ICMM) system, and the improvements that can be achieved through the use of the system.

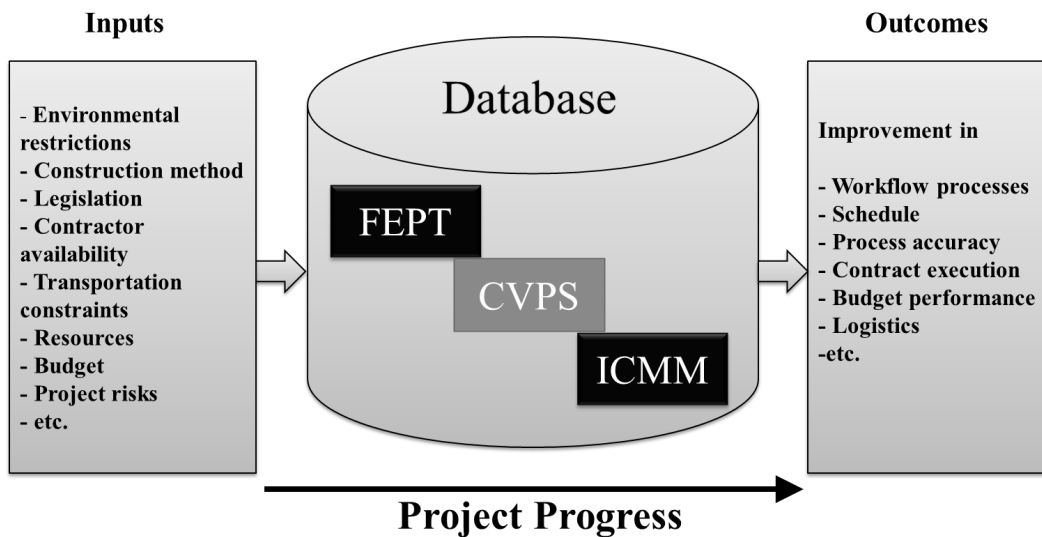


Figure 4-1: FEPT and Other Elements of the Advanced Construction Supply Nexus Model (ACSNM)

A review of the literature indicated that efficient FEP leads to higher levels of project performance but that the execution of numerous activities and the production of deliverables are required in a compressed time period. Schedule and budget limitations create pressure to minimize costs and the time spent in planning. Existing IT systems contribute little that can address these pressures. By facilitating collaboration among stakeholders in diverse locations with the use of workflow-enabled processes, such pressures can be reduced, and the overall process and results of FEP can be improved. To achieve these goals, an FEPT model has been developed through collaboration with the Coreworx

company as support for owners and major contractors (EPCs) who are engaged in FEP. The tool is based on workflows implemented in an Electronic Product and Process Management System (EPPMS). This chapter presents the developed FEPT model and describes how it can be used for construction megaprojects in the nuclear power, oil and gas, and mining industries. The chapter begins with the definitions related to and an explanation of the general process for implementing and applying the FEPT and then describes and analyzes how some of the components of FEPT were applied in a number of mega construction projects. The results indicate that the FEPT has the potential to increase FEP efficiency and effectiveness for the megaprojects in the construction industry.

Recent customer data from Coreworx Inc. show that the bulk of the project costs, the major risks, and the interfaces are defined during the FEP stage. Using appropriate tools to facilitate informed decisions early in the process is, therefore, critical so that measurable improvements can be realized with respect to the cost, scheduling, and change orders for the overall project. The largest and most challenging FEP deliverable is a level of design sufficient to enable the project team to prepare cost and schedule estimates. While the work involved in drafting the design materials is significant, the process is well understood and is executed by experienced engineering professionals who use established tools. Despite this advantage, the requirements associated with FEP design activities for a major capital project can entail significant challenges associated with the following:

1. Collaboration between the owner and the engineering contractor(s)
2. Hundreds or thousands of design and planning documents transmitted, archived, and indexed for use by a variety of stakeholders who have differing needs
3. Timely review and authorized approval of all deliverables
4. Full information handover to procurement and detailed design teams at completion
5. Little time or budget allocated to the implementation of hardware or software technology to support this process
6. Identification and communication requirements with respect to the relationships between the scope of work for multiple activities and the physical and non-physical interfaces between organizations
7. Risk identification and assessment

For capital construction projects, the engineering contractor usually produces the design under the supervision of and in consultation with the owner. The parties should work according to a common

plan and structure so that the mountain of documents and correspondence is controlled and accessible to each party. If project funding is approved, the design deliverables from the FEPT become the primary input into the subsequent phases of the project life cycle, which introduces an additional set of information indexing and handover requirements in order to make the FEP deliverables useful to the procurement or detailed design teams.

With each revision requiring review and approval, the FEP team faces an enormous challenge, given that the FEP schedule spans only a few months from start to finish. The tight schedule typically also makes many of the options that the FEP team may have considered infeasible with respect to software and hardware implementation for managing information and processes. In this research, consideration of these challenges led to the development of an information technology (IT) system and service for support of FEP activities. The FEPT model was thus designed to be an on-demand solution that addresses the specific needs of owners and contractors who are engaged in front-end planning. This tool also needs to meet the requirements of an ACSNM. The FEPT is comprised of a set of services, processes, and access methods for managing planning activities and deliverables (Figure 4-2). The author contributed primarily to the design and definition of the processes and access methods. This part of research was performed through collaboration with Coreworx team. Phase 3 of the FEPT particularly has been designed to meet the developed model's requirements.

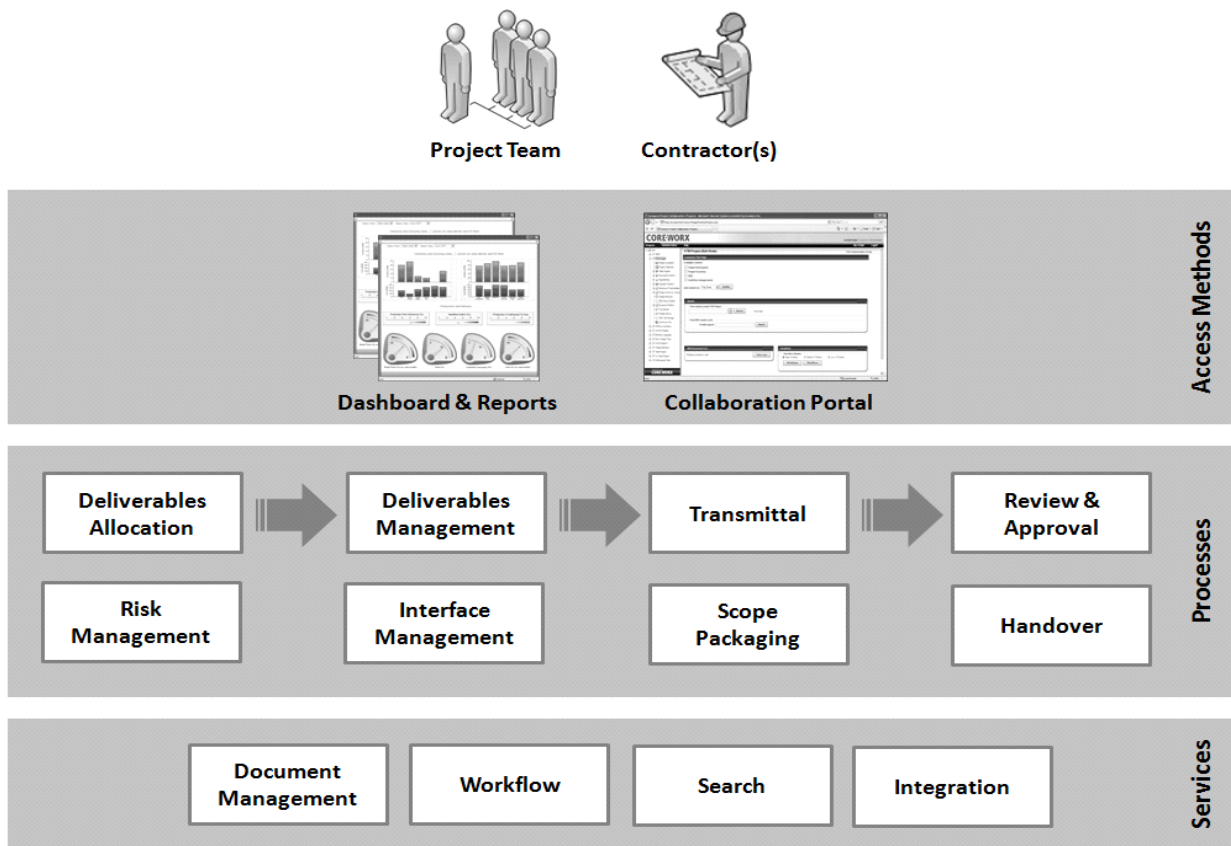


Figure 4-2: FEPT Components Implemented in the System

Since all of the activities and deliverables in FEP involve documents, strong document management and search services (bottom row of boxes in Figure 4-2) facilitate the archiving and retrieval of documents and metadata, along with workflow services that support the process automation requirements. Integration features enable the exchange of data, such as the schedule and the work breakdown structure, with other project systems.

Process elements (middle rows of boxes in Figure 4-2) are critical for efficiently routing information through the activities related to planning. These are the integrated processes implemented with the use of the services described in the preceding paragraph, which link together a series of related activities and shared data so that the planning work can be executed in a consistent, efficient, and predictable manner. User interfaces (top row of boxes in Figure 4-2) provide easy access that facilitates the coordination and monitoring of planning activities and deliverables.

In FEP initiatives, time allocations normally include neither allowances for implementing significant software or hardware infrastructure nor significant budget amounts for IT resources. Considering that

the FEPT life span matches that of the FEP itself and is usually no longer than a few months even for the largest projects, the FEPT is provisioned online, also known as “in the cloud,” requiring only a web browser and login in order for users to participate. Further details about these components are provided in subsequent sections. In this research, the required services, processes, access methods and other components for developing the FEPT are modeled on an EPPMS platform provided by Coreworx Inc., the partner in this research. The following section illustrates the development, key functions and components of the FEPT.

4.1 FEPT Development and Implementation

The FEP process sets the priorities and timing for the initiation of a capital construction project in a way that will meet the overall objectives of the owner or main contractor, and requirements of the developed ACSNM. The FEPT can be used for managing three FEP phases: feasibility, concept, and detailed scope. These phases are described briefly in the Chapter 2, but the next sections provide detailed definitions, followed by an explanation of the development of the FEPT system. These phases tend to be primarily owner driven. It should be noted that this part of the research contributes to the improvement of the feasibility and concept phases; however, the main contribution was developing a structure for the detailed scope phase considering the ACSNM’s requirements. This provides a foundation for applying the Construction Value Packaging System (CVPS) which is explained in the next Chapter.

4.1.1 FEP Phases

In Phase 1, the feasibility analysis, all potential options should be developed and documented. In other words, this phase is a preliminary investigation into the potential choices associated with a construction project. These options should then be evaluated against a set of agreed-upon criteria. The report resulting from this phase also recommends a course of action and a realistic estimate of the range of the total end costs and life cycle costs of the project. All factors that could affect a desirable outcome, such as the resources available, the time frame, any outsourcing strategy, the facilities, and any environmental issues, must all be addressed and analyzed.

In Phase 2, the concept development or perception phase, each of the alternatives contained in the feasibility report is analyzed based on mission requirements or business objectives, the scope of the project with respect to fulfilling the mission or objective, and the justification for the project. In other words, once all potential options have been developed and agreed upon by the client, the project team

endeavors to create, analyze, optimize, and specify the many aspects of the process parameters, philosophies, and equipment, thereby developing a basic definition of the project. The options identified in the earlier feasibility phase are developed by the project team to a degree of definition that enables project budgets to be accurately assessed and implementation schedules to be set. When all the alternatives have been analyzed and the best option determined, the basic project definition, i.e., the concept report, is then completed, in readiness for the next phase.

Phase 3, the detailed scope development, includes an outline of the main features of the project: the general design, approximate benefits and costs, sources of funding, risk factors involved, the basic organizational structure, interfaces, and a preliminary execution plan (the initial estimate, initial schedule, and safety strategy). In this phase, the definition of the scope of the project is finalized, and the cost/schedule estimate is prepared. Utility requirements are also identified, governmental and environmental restrictions are documented, and an initial site plan is formed. The main output of phase 3 of the FEP consists of a strategic plan for the construction project, which is used as the basis for selecting contractors, defining a work breakdown structure, developing work packaging, identifying work packages and contractor interfaces, considering risk management (Stephen et al., 2007), and beginning the detailed design and other construction project phases.

Lack of a comprehensive strategic plan may lead to a fragmented supply chain approach that creates significant problems (Konukcu et al., 2008). The strategic plan and other reports produced during this phase thus enable the project team to ensure that the project progresses smoothly to the execution phase. The deliverables for this phase include a strategic plan as well as the following:

1. Cost estimation and execution strategy in readiness for the final investment
2. Risk drivers associated with the project
3. Categorical definition of the physical and non-physical interfaces (80 %)
4. Effective reports presented in a ready-to-use format that will facilitate the selection of the contractors (Laryea and Hughes, 2011)
5. Investment cost estimate associated with the corresponding FEPT documentation
6. Reports detailing instrumentation, civil, electrical, and piping requirements, such as a piping and instrumentation diagram (P&ID)
7. Detailed scope of work to be used for defining work packages

Phase 3 represents the majority of the time and deliverables required, so the FEPT developed in this research was designed primarily to address the requirements associated with this phase. An

understanding of these phases and of FEP fundamentals was the first step in the development of the FEPT model.

4.1.2 Development of the Front End Planning Tool

The ACSNM requirements analysis is the first step in the development process. Since the components of the FEPT could be customized according to principles of the ACSNM, all alternatives should be evaluated during this phase. For the most desirable features to be determined, the FEPT incorporated the opinions of management and the project team experts with respect to costs, technical features, and system benefits.

Once the ACSNM characteristics were analyzed, the FEPT design phase then illustrates how the FEPT can fulfill these requirements. The FEPT design then phased into a fully operational ACSNM, beginning with the transformation of the ACSNM specifications and requirements established during the ACSNM characteristics and features analysis. The automation of the document control functions was also performed in this phase and included metadata population, package creation and integrity checking, version control, approval workflows, exception alerting, and transmittal receipt/generation. Following this step, the test plan was then developed to ensure that the system is ready to be used and that it can be formally accepted. The test plan was reviewed and evaluated by experts (construction project managers) in order to verify that the proposed model is appropriate for the specific types of application required.

4.2 Key FEPT Functions

The FEPT has been modeled as an online system that addresses the specific needs of the owners and contractors who manage FEP information deliverables. The FEPT is designed to link to the work breakdown structure (WBS) and the baseline schedule from Primavera P6 in order to establish the scope of work and individual work packages. With each work package, the FEPT associates configurable milestone sequences, planned start and finish dates, and planned hours. Each FEP document deliverable is then assigned a weight within a package, along with the planned, actual, and forecast dates for each document milestone. Figure 4-3 summarizes the FEPT elements that organize and monitor the schedule with respect to scope, packages, deliverables, and milestones.

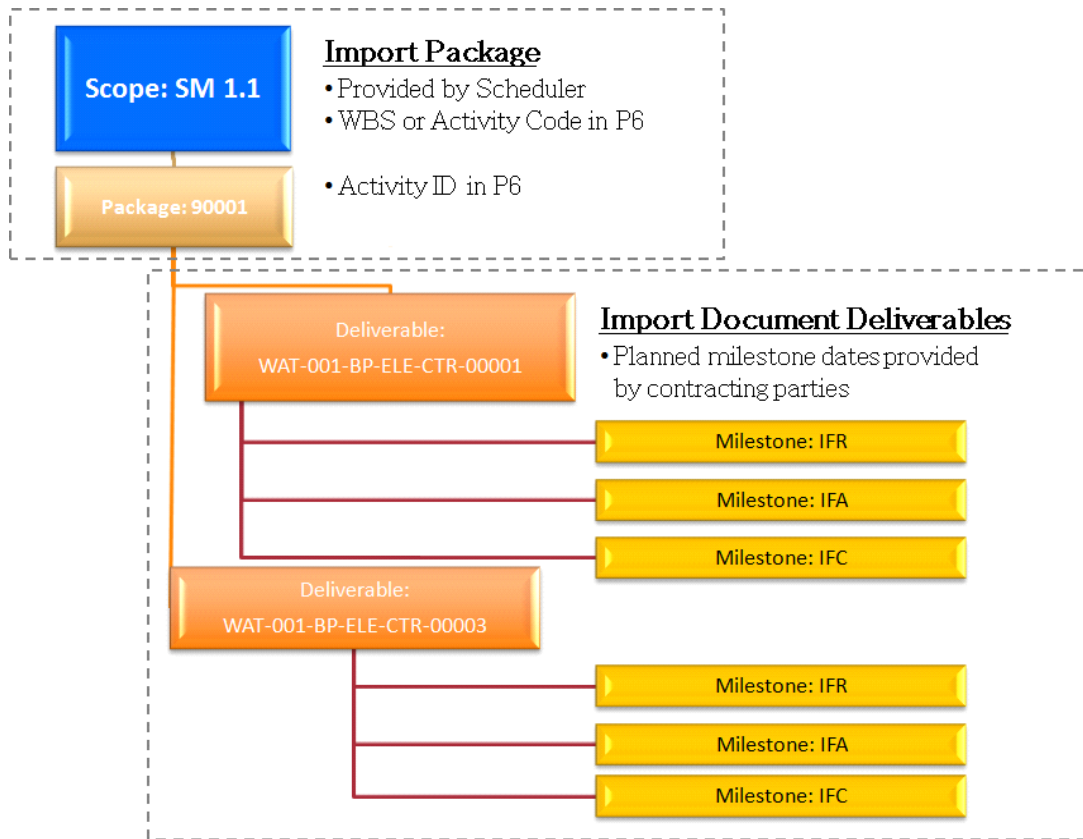


Figure 4-3: FEPT Scope, Packages, Deliverables, and Milestones

With this configuration in place, based on the milestones achieved for the deliverables, the FEPT has the potential to measure the engineering earned value and schedule performance at each level.

A document management system, as presented in Chapter 7 of this thesis, securely controls all information associated with the FEP and includes features for managing metadata, revisions, relations, and the audit history. With limited time and resources, the FEP team must adopt a proven procedure for project-based document control. The FEPT includes pre-configured document metadata templates based on ASME standards for design, correspondence, and plan documents. The FEPT uses a collaboration website where the owner’s FEP team and the design contractors can interact.

As explained previously, FEPT was developed based on a full-scale EPPMS solution through Coreworx Inc, which is a completely secure site, with user login accounts and permissions that enable each party to quickly access the planning information required for their specific role(s). A sample page is shown in Figure 4-7.

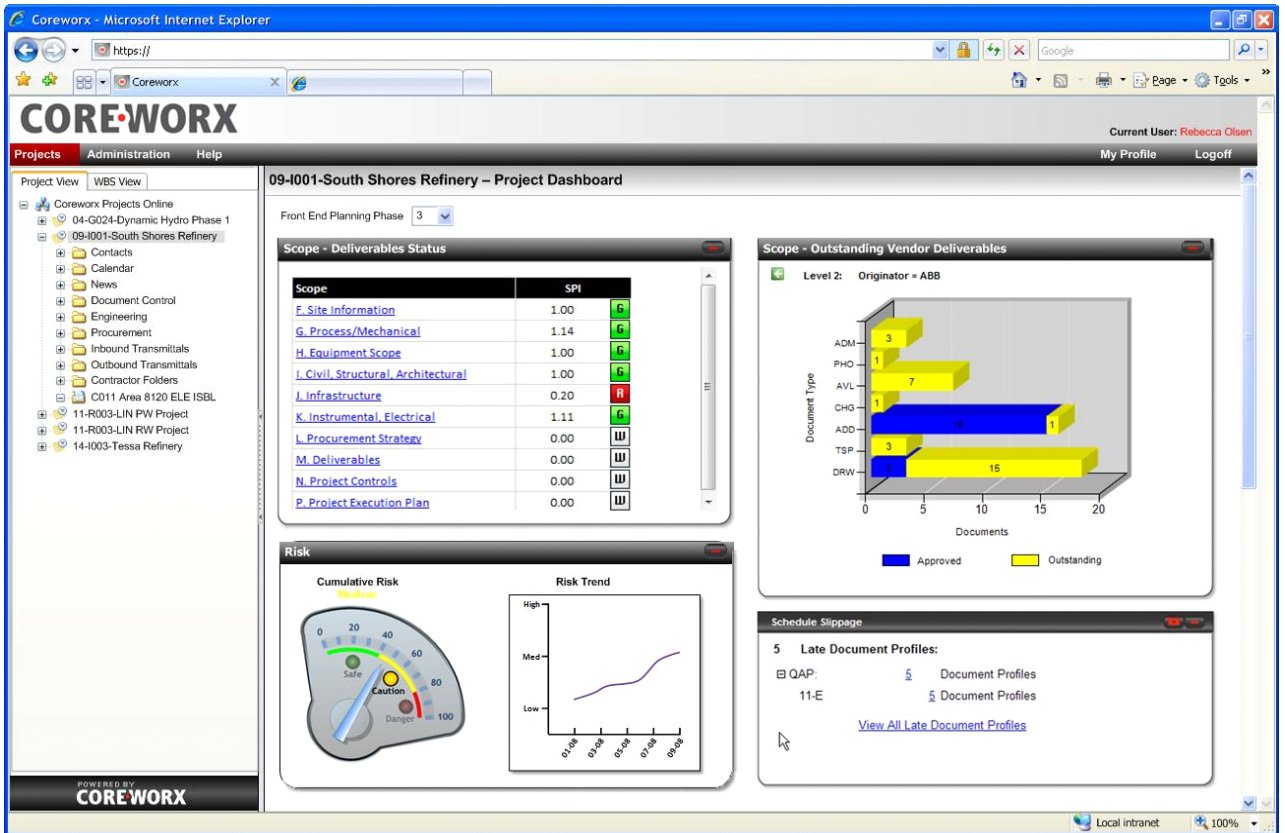


Figure 4-4: FEPT Collaboration Site

A standardized work process increases the efficiency of the engineering team during the FEP design phase. The use of a pre-configured workflow also increases the rigor that is applied to the work process of design reviews and equips the engineering team to accurately track the resolution of comments regarding nonconforming items. Figure 4-5 illustrates a portion of this process.

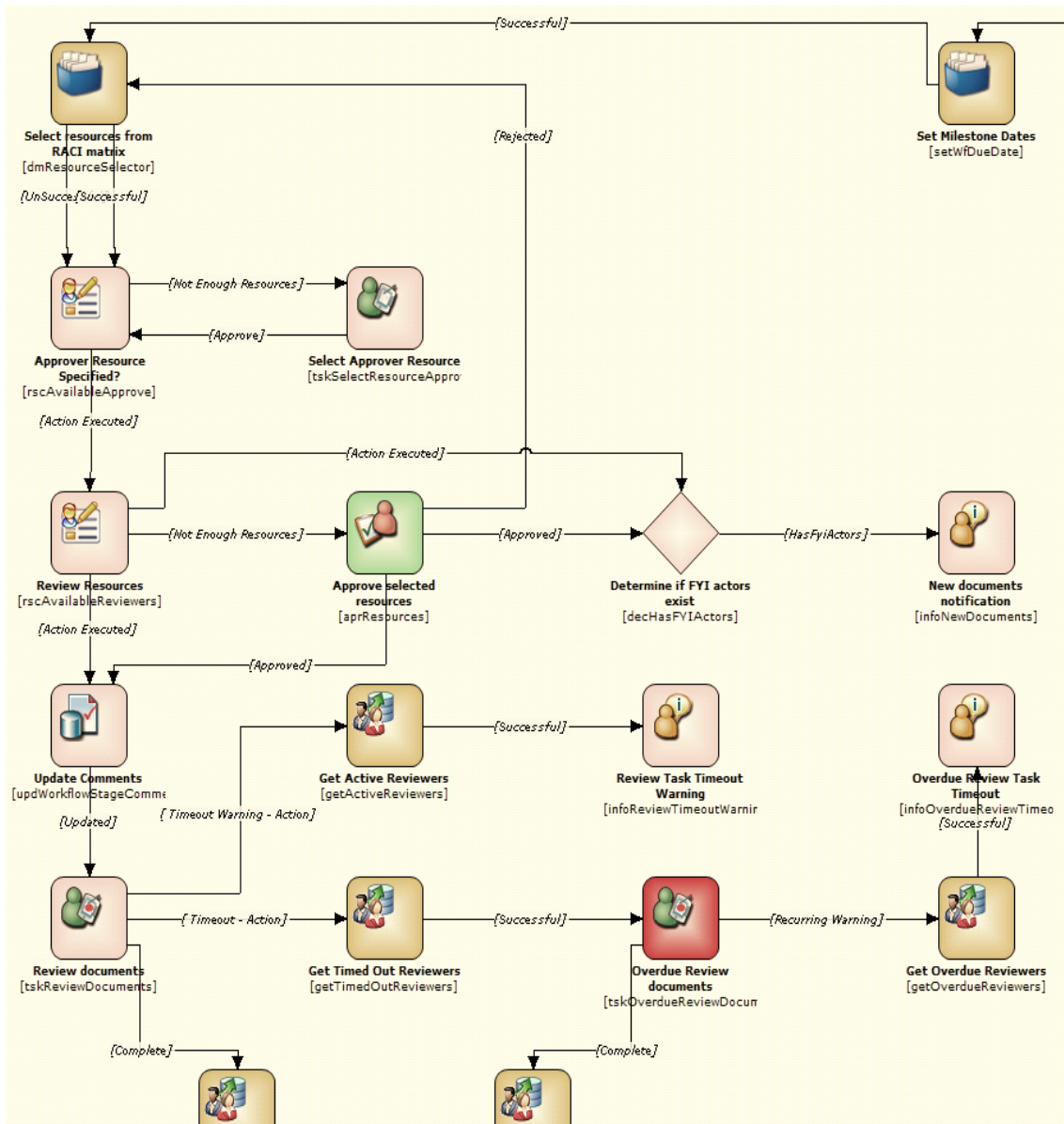


Figure 4-5: Partial Map of the Design Review and Approval Workflow Process

Inbound transmittals as one of important components of the FEPT provide an automated process for the controlled exchange of documents and verification rules. The transmittal is a zipped (.zip) file that contains both document deliverables and a transmittal cover sheet. The FEP design contractor uploads the transmittal to a pre-configured folder on the collaboration web site. The files are then imported into a controlled archive, which incorporates additional validation in order to ensure that the files and

metadata comply with the organization’s FEP standards. The FEPT therefore has the potential to generate outbound transmittals and send them to the FEP contractor or other stakeholders.

The FEPT model includes a change management work process that adds control and visibility to changes in FEP activities and information. All changes must be reviewed and approved by the appropriate authorized individuals. To keep activities and deliverables on schedule, the FEPT provides progress tracking and performance measurement tools. As each document deliverable progresses through its life cycle stages, from allocation to submission to approval and issue, the FEPT can provide the functionality needed to automatically trigger milestones, providing the highest level of accurately reported progress. Reports can provide real-time visibility for team members and other stakeholders, including calculated progress and performance metrics. FEP teams and stakeholders can have the capability to generate an “FEP Scorecard” (Figure 4-6) to monitor the overall schedule performance index (SPI) for each element of the scope of work. The FEPT can therefore enable the selection of which scope-of-work elements (aligned with the WBS codes in the schedule) to include in the scorecard. The SPI is calculated for the scope of work for each work package.



Scope	SPI	
01-E	0.50	R
01-F	0.50	R
07-A	1.63	G
07-C	1.83	G
07-E	1.75	G
07-F	1.85	G
13-A	0.99	Y
13-D	1.71	G
13-E	1.25	G
13-F	1.50	G

Figure 4-6: FEP Scorecard

As work progresses and incremental deliverables arrive from the FEP contractors, the FEPT has then the potential to determine which aspects have changed from one submission to another (Figure 4-7).

COREWORX

Deliverables Comparison Report

Sunday, March 28, 2010 2:38:46 PM

Schedule Id: MCP-CWX-DDS-CWX-00022

Originator: CWX

Revision New Schedule Old Schedule

A06 A05 A05

Imported Date 03/05/2010 03/05/2010

Added Documents

Scope	Package	Document Id	Revision	Wgt	IFR	IFA	IFC
SM 1.1	90001	WAT-001-BP-ELE-CTR-00003	A01	30	01/31/2010	02/24/2010	03/11/2010

Deleted Documents

Scope	Package	Document Id	Revision	Wgt	IFR	IFA	IFC
SM 1.1	90001	WAT-003-YG-TRI-NCR-00001	A01	10	02/01/2010	02/10/2010	03/11/2010

Missing Documents

Changes to Document Deliverables

Scope	Package	Document Id		Wgt	IFR	IFA	IFC
SM 1.1	90001	WAT-001-BP-ELE-CTR-00001	New:	10	01/27/2010	02/25/2010	03/11/2010
			Old:	10	01/27/2010	02/24/2010	03/11/2010

Figure 4-7: Comparison of Deliverables Report

The FEPT can also provide a report that identifies any disparities between the planned and actual delivery dates (Figure 4-8).

COREWORX

Deliverables Discrepancy Report

Sunday, March 28, 2010 2:59:44 PM

Deliverable List: MCP-CWX-DDS-CWX-00022

Current Revision: A06

Originator: CWX

Variance Filter (Days): -1

Imported Date: 03/05/2010

Scope	Package	Document ID	Rev		IFR	IFA	IFC
SM 1.1 Sandra Mac 1.1	90001	WAT-001-BP-ELE-CTR-00001	A03	Planned	01/27/2010	02/25/2010	03/11/2010
				Actual	03/28/2010		
				Forecast	03/28/2010		
				Variance	-60		
		WAT-003-NI-MEC-PHY-00001	A02	Planned	01/24/2010	02/06/2010	03/11/2010
				Actual	03/05/2010	02/10/2010	
				Forecast	03/05/2010	02/10/2010	
				Variance	-40	-4	
		WAT-004-NI-MEC-PHO-00001	A02	Planned	02/27/2010	02/28/2010	03/11/2010
				Actual	03/03/2010		
				Forecast	03/04/2010		
				Variance	-4		

Figure 4-8: Discrepancies in Deliverables Report

The FEPT model also includes a schedule slippage report for monitoring document deliverables that have either a late start or a late finish (Figure 4-9). The document details in each package constitute the criteria for monitoring planned versus actual start and finish dates for each document deliverable.

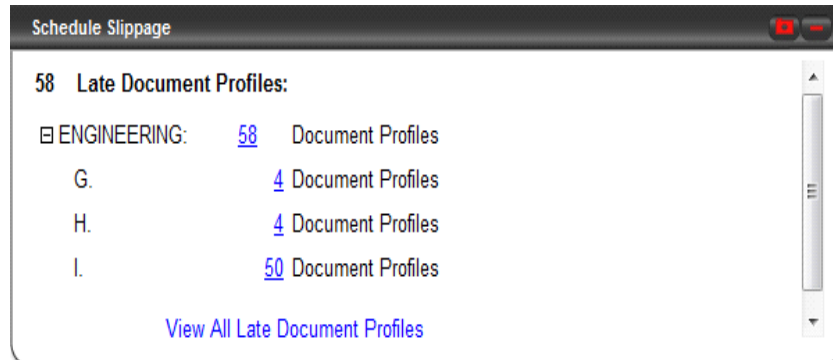


Figure 4-9: Schedule Slippage Report

4.3 FEPT Advantages and Challenges

This section discusses the advantages of the FEPT and the challenges associated with its implementation.

4.3.1 Advantages of the FEPT

The FEPT model has the potential to help with the management of FEP activities and deliverables with a focus on control and compliance, transparency, and efficiency. These advantages are detailed in the following sections.

The adoption of a front-end planning tool sets a high quality standard for information integrity during both FEP and the balance of the project through the application of consistent treatment of every deliverable with regard to: (1) archiving and access; (2) naming and numbering; (3) versions; (4) metadata values; and (5) milestone achievements, rules of credit, and the tracking of connections with other information items. The tool can potentially enforce governance and compliance with workflow task assignments and sequence and ensures valid authorization for the execution of tasks and for access to reporting information. Each information item is subject to identical processes (e.g., change management approval) and audit history, so authorized users can rely on a single view that incorporates all events and interactions that have affected the information during its full life cycle. If the information managed by the FEPT continues to be used during subsequent project phases, then organizations will benefit from the extended management of information relationships and history.

Front-end planning is characterized by a large volume of documents that must be captured, transmitted, validated, reviewed, and approved. This process has traditionally been accomplished with the use of a mix of printed copies, emailed messages, couriered document packages, and handwritten mark-ups, with spreadsheets to keep track of all of these materials. Through a full-scale EPPMS system, such as Coreworx EPPMS, the FEPT can quickly move electronic versions of this information between participants and stakeholders, and includes verification that correct document versions have been provided, thus reducing the chances of error and the necessity for rework. The FEPT can also provide electronic design review and mark-up tools that improve the efficiency of the engineering team without the requirement for special software. Workflow timeouts, delegation, and escalation policies function to keep activities on schedule, and the FEPT alerts the appropriate controllers to take action when bottlenecks occur. The entire system is automated using services such as the workflow engine and is hosted on servers.

The FEPT can help balance and optimize work and resources. Work items are assigned a relation to the critical path so that each participant prioritizes work according to the requirements of the schedules. The FEPT model of this research also suggests the application of a project Responsible-Accountable-Consulted-Informed (RACI) matrix in order to ensure that the workflow structures automatically direct activities to authorized team members, and that associated reports provide oversight with respect to the appropriate assignment of users to the correct authorized roles and activities. Figure 4-12 shows a partial RACI matrix, according to which documents are routed based on their discipline and document type. Metadata values and authorization levels are associated with team roles (e.g., approver, reviewer, consolidator, and informed).

DISCIPLINE - Discipline	DOCTYPE - Document Type	Work Group Assignment	Engineering Reviewers	Project Managers	Engineering Approver	Engineering Manager
CRR	RPT		R	R	A	M
CRR	RPT				C	
CRR	*		R	I	A	M
CRR	*				C	

Figure 4-10: Subset of a Sample RACI Matrix

Compressed schedules for front-end planning force the project team to closely monitor progress and performance. The FEPT model integrates with the schedule data so as to provide performance metrics and also calculates the earned value based on configurable milestones for each work package and its related deliverables. Estimation activities and executive decisions demand that a level of completion be associated with the deliverables before all planning is completed, so the FEPT provides summary and detailed reports broken down by scope of work, contractor, information type, or other criteria. Reporting also facilitates the identification of problems as they begin to occur, which enables immediate action and helps measure the impact of actions in real time.

Owners and contractors draw a clear distinction between the planning phases and the execution of the project after it has been approved. This distinction usually includes entirely different teams and partners who use different systems. Project execution teams, such as procurement and engineering, often rely on the data from the FEP phase to serve as a baseline for their activities and deliverables. For this reason, the handover of planning data is critical to the success of a project. The FEPT enables information handover packages to be assembled more efficiently, in either hard copy or electronic format, because the details have all been archived electronically during the first three phases of the FEP.

4.3.2 Challenges Associated with the Implementation of the FEPT

The lack of communication and the resistance to change that is inherent in traditional approaches to the construction industry have a direct effect on the extent to which new methods are adopted. The main barriers to the implementation of the FEPT include, but are not limited to, the following:

1. Schedule constraints: even the largest megaprojects rarely have FEP that extends beyond 24 months, so the time required for implementing and learning a new tool is often prohibitive.
2. Budget limitations: FEP budgets are commonly set at 1% of the total installed value of a project, which may not accommodate FEPT licensing, implementation, and support.
3. Contractual terms and methods: Owners and engineering contractors may not agree on the systems and tools required for executing the FEP work.

4.4 Example Projects

The developed FEPT model offered effective functionality, including collaboration, document control, workflow, and interface management. Because of the constraints involved in validation of the developed FEPT model, the performance of the different components of the model were evaluated on

a number of major capital projects in collaboration with Coreworx Inc, the research partner of this project. It should be noted that FEPT model, as designed for the ACSNM framework of this research was not implemented on these projects, however, the functionalities and capabilities that were exploited in developing the FEPT model for ACSNM are very similar to those used by FEP tools in these projects. Although this method does not provide a comprehensive validation, it was taken as evidence that the components of the model behaved effectively.

The FEPT has been used worldwide for major capital projects that are driven by the need to accelerate the completion of the FEP stage and to improve the quality of the FEP deliverables. This section presents three case studies that were conducted in order to verify the effectiveness of the components and the potentials for the successful implementation of the FEPT model. Due to confidentiality restrictions, the actual names of neither the construction companies nor the projects can be included. Lessons learned from the case studies are presented in Section 4.5 of this chapter.

4.4.1 Project 1: Oil Sands - 2010

This project is located in northern Alberta, Canada. During the planning stage, more than 40 subcontractors worked directly under the main contractor. The project has a 2020 time frame, with production expected to reach 200,000 barrels per day once all phases have been built and are operational. . A number of activities occurred prior to the official initiation of this project, providing much of the business requirements and subsequent solution design including proof of concept; demonstrations, and workshops.



Figure 4-11: Activities Prior to the Official Initiation of FEPT

In 2009, the project owner engaged the research and development (R&D) team to provide an FEPT to support the collaboration and document control needs at the planning stage. A primary requirement was that the FEPT function as part of an integrated project information management system. The

integrated system would provide a bridge between the information developed in the FEP stage and the deliverables to be managed during the execution of the project.

The FEPT framework was used to manage the engineering documents, deliverables (technical and non-technical), and datasheets, excluding loop numbers, piping isometrics, and specialty piping deliverables. The tool enabled the migration (bulk importing) of all pre-allocated engineering deliverables and interfaces and included a work-in-progress area where users of the system could access both a personal workspace and shared workspaces. The multiple functional teams utilized several other features: contact lists, links to web pages, shared document areas, news feeds, and forums.

The contractor completed the FEP for Phase 1 of the project and obtained the necessary approvals from the Government of Alberta, the Environment Department, and the Energy Resources and Conservation Board (ERCB) so that the project was ready to begin in 2010. The contractor's CEO stated that the overall cost estimate for Phase 1 of the project decreased by almost \$1 billion during the course of the design optimization, and the project was also set to achieve a solid sustainable economic return based on current market conditions for Phase 1.

4.4.2 Project 2: Deepwater Gas Field Development - 2010

This case study project, a partnership between two major oil companies in North America and Asia, is located in the South China Sea at an average water depth of 1,300 m.

In 2010, the owner partnership signed an agreement specifying the key principles of cooperation for the funding and operation of the deep-water gas field development. The owner partnership and Project Management Contractor (PMC) then awarded lump sum contracts for the scope of three major packages. FEP was completed, and the overall development plan was submitted to regulatory authorities in 2011.

The owner partnership initially intended to use the PMC's systems for FEP, but recognized the inadequacy of these systems. Instead, they preferred a cradle-to-grave application that would record documentation in the planning stage and consistently track and manage it throughout the execution and into the operational phase. Evidence of lost information was the primary driver leading to this decision.

The project employed the basic FEPT framework for the management of new engineering documents and deliverables (both technical and non-technical) from the three primary EPCs, project

correspondence, existing FEP documents, and interface documents. The transmittal functionality of the FEPT facilitated the exchange of information with the contracting parties. Workflows provided control of the review and approval of the deliverables. The vendors were overseen by scope-of-work managers, and administrators granted the parties sufficient access privileges to enable them to exchange information with the project team. It should be noted that 2,800 to 3,500 documents were generated and managed using the FEPT processes.

To enable the initial use of the system as quickly as possible, the FEPT functions were rolled out in controlled implementation phases: data storage, vendor documents, and enhanced functionality. Phase 1 (data storage) was focused on moving all project data from the legacy project information system into the FEPT, with the goal of making it easier for project team members to find information. This phase included the migration of the most recent version of the documents as well as any project correspondence. Phase 2 (vendor documents) was concentrated on the management of vendor documents, including inbound transmittals, review/approval workflows, and vendor data storage. Phase 3 (enhanced functionality) included the functionality for managing technical queries to and from vendors, interface management agreements, change requests, and enhanced processes for reviewing deliverables through the use of comment sheets and forms.

In 2012, the owner partnership reported that the project was advancing as planned, with the completion of the initial major component and the next significant components scheduled for the second quarter of 2013. The front-end engineering and design work for the development of the next gas field is underway. The development is on target for the first production to occur in late 2013 or early 2014.

4.4.3 Project 3: Gladstone Liquefied Natural Gas (GLNG) - 2010

A major North American EPC contractor has utilized different levels of FEP tools for dozens of major projects around the globe. This contractor was awarded the Front-End Engineering and Design (FEED) contract for a major portion of the Gladstone Liquefied Natural Gas (GLNG) upstream project, one of the world's largest projects for converting coal-seam gas to liquefied natural gas. The contractor's scope of work for this contract included the preparation of an execution plan and a cost estimate for the engineering, procurement, and construction of the upstream facilities required in order to deliver coal-seam gas from coal-seam gas fields in northeastern Australia to the proposed GLNG liquefaction facility to be located in Gladstone.

The contractor used the FEPT with more than 150 offshore experts from its United States headquarters. The FEP stage was completed in late 2011.

4.5 Lessons Learned

This section presents the results of the most recent case studies and summarizes the lessons learned from the experts and the FEPT users. These observations are derived from experience with more than 10 projects:

1. For a multi-billion dollar project, a typical FEP duration is 12 to 24 months. Approximately 100-150 people can be involved at any given point, about 50 of whom are commonly the owner staff, but a rule of thumb that should be applied is to improve decision making by using enough owner expertise with the capacity to challenge what the engineering contractor puts forward during the FEP process.
2. Because the goal of FEP is to obtain sanctioning for the project to move forward as quickly as possible, based on a detailed scope of work, cost estimates, etc., organizations fail to allocate sufficient time for the implementation of information systems such as the FEPT. An FEPT system must therefore provide a quick path to valuation with minimal implementation requirements.
3. Before starting FEP, the project team must clearly communicate the need of an FEPT and other IT infrastructure and systems.
4. At the end of the FEP stage, the project managers normally conduct a gate review, called a "Project Readiness Assessment," which is an examination of all aspects of the FEP and which assures the owners in advance of project sanctioning that the project can be executed within expectations.
5. The ability of the FEPT to integrate with a full project information management system enhances its value by providing consistency throughout the project life cycle, by building a traceable relationship between the FEP and the execution deliverables, and by preventing the loss of information.

The performance of construction megaprojects can be improved with the implementation of FEP. However, the FEP process is normally constrained by tight schedules and limited resources. The main FEP deliverables are a level of design sufficient for the preparation of cost and schedule estimates

that will then be used to determine authorization for project expenditures. Using a FEPT can potentially be helpful in increasing the efficiency and control of the FEP process. The FEPT presented in this thesis provides rapid implementation of a solution that can accommodate a compressed schedule while supporting an enhanced level of control and quality with respect to FEP deliverables.

Chapter 5

Construction Value Packaging System

In recent years, the construction work packaging systems have been investigated by many researchers who have employed a variety of methods and concepts. Some of these studies were explained and discussed in Chapter 2. This Chapter presents the Construction Value Packaging System (CVPS), as an alternative to the existing construction work packaging systems, based on requirements of the Advanced Construction Supply Nexus Model (ACSNM). Through the application of the value packaging concept in construction projects, the CVPS can improve the performance of the construction supply chain process.

In large construction projects, optimally dividing and then packaging the work among contractors and suppliers is challenging. This procurement process is typically executed during the pre-construction phase by a project leadership team, who rely on their experience and judgment, making it difficult to demonstrate that the results are optimal or to explain the rationale after the fact. Addressing these problems requires an auditable and robust method that still incorporates the expertise of the project leadership team. This part of our research therefore included the creation of a comprehensive Construction Value Packaging System (CVPS) that serves as a computational and process environment for helping project leaders increase the efficiency, auditability, and effectiveness of the procurement process. The development of this system required the definition of a new concept called the construction value unit (CVU), whose scope covers value-added work defined by the type of activity, its stage in the value chain, and its specifications. Construction value packages (CVPs) are comprised of CVUs. The research results presented in this thesis show that the CVPS has the potential to improve the contract management of an enterprise-wide construction supply chain.

The scope of knowledge required for conducting the planning phase is influenced by the context of the type of project and the job situation (Edum-Fotwe and McCaffer, 2000). The development of the CVPS therefore included consideration of the size, location, and schedule of the project as well as any cash flow constraints, the owner's philosophy, and the overall project strategies, all of which are discussed in the following sections. Nevertheless, the model created through this research is not based solely on one specific type or location of facility but was developed from the perspective of breaking down projects into controllable and practicable CVPs.

In this approach, a project is broken down into Construction value packages (CVPs) during the work breakdown structure (WBS) phase. The front-end planning tool (FEPT) and the WBS processes provide all the elements and information necessary for developing the Construction Value Packaging System (CVPS), which is obtained from an analysis of the construction work and its separation into discrete work packages that cover a scope of work appropriate to be awarded to a contractor, vendor, or fabricator. Figure 5-1 gives a snapshot of the basic architecture, components, and data flow of the system. The size of a CVP should be suitable for execution by a contractor. In other words, the scope of work associated with the CVP should be large enough that it could be performed using the services of a contractor. “Previous research has been devoted to examining the conceptual applicability of the construction work packaging concept and applying it as a general managerial tool. Only limited attention has been paid to the actual construction packaging process” (Kim and Ibbs, 1995). This phase of the project entails the greatest risk because it represents the starting point of dealings with the contractors and other external parties involved in a project. The following section contains effective guidelines for managing this phase through the CVU concept and for then selecting reliable contractors. The system algorithm incorporating the Construction Value Units (CVU) will subsequently be provided in Section 5.1 of this Chapter.

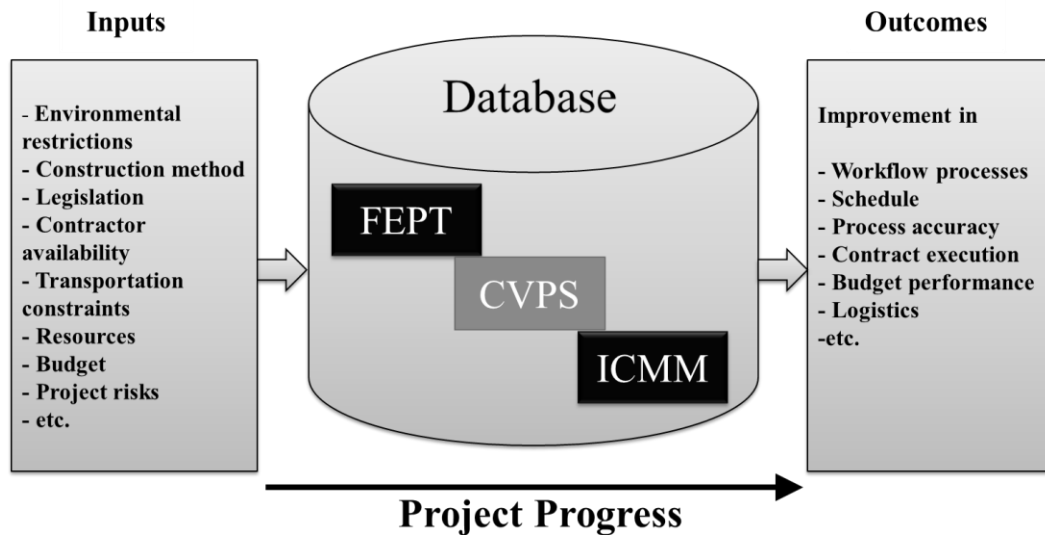


Figure 5-1: Value Packaging System and Other ACSNM Elements

Before beginning this phase, the project team should identify the scope of work to be carried out under individual contracts and must also arrange the prequalification form for the bidders' list for the scope of work for each subproject to be subcontracted (Appendix A). The contractors, fabricators, and vendors should provide the information requested and any supporting particulars necessary for a complete analysis of their quotation, such as special tools and lift fixtures, technical services, field service representatives, shipping/transportation, instruction manuals, and operating/maintenance spare parts (Appendix B, C).

As mentioned, the detailed scope phase results in the identification of the components required for the design phase, which begins during and after the front-end planning (FEP). During the former phase and, in some circumstances, the latter, the value units are defined, with consideration given to the WBS and other outcomes of the FEP process. CVUs can regularize and integrate all planning-related processes so that the delivery of all tools, equipment, and required information can occur prior to the start of the bidding and execution processes. This phase of a project incorporates a CVU based on a definition of the process. This work presented in this thesis included an attempt to define a CVU based on its components, a definition not found elsewhere: The value unit is a specified scope of work defined by methods, stages, and places of fabrication. A value unit is usually associated with the following:

1. A list of potential contractors, a sample of which is shown in Figure 5-2, which is a snapshot of a contractors' list in the proposed system
2. The location and method of the work, e.g., on-site, off-site, fab-shop, etc.
3. Drawings
4. A detailed description of the scope of the work
5. A detailed bill of materials (BOM) that specifies all quantities that make up the scope of the work
6. Human resources information
7. A list of fixtures, fittings, and equipment (Example-Appendix G)
8. A process schedule that details the commencement and completion dates and also includes detailed schedules and spreadsheets that indicate the tracking, monitoring, and closing out of all activities from the start to the completion of each process

9. An inventory policy
10. A plan of all movement on-site
11. Technical requirements, references, and information
12. Quality assurance (QA) for auditing all materials and modules (Raymond, 2002)
13. Transportation issues related to potential module deliveries

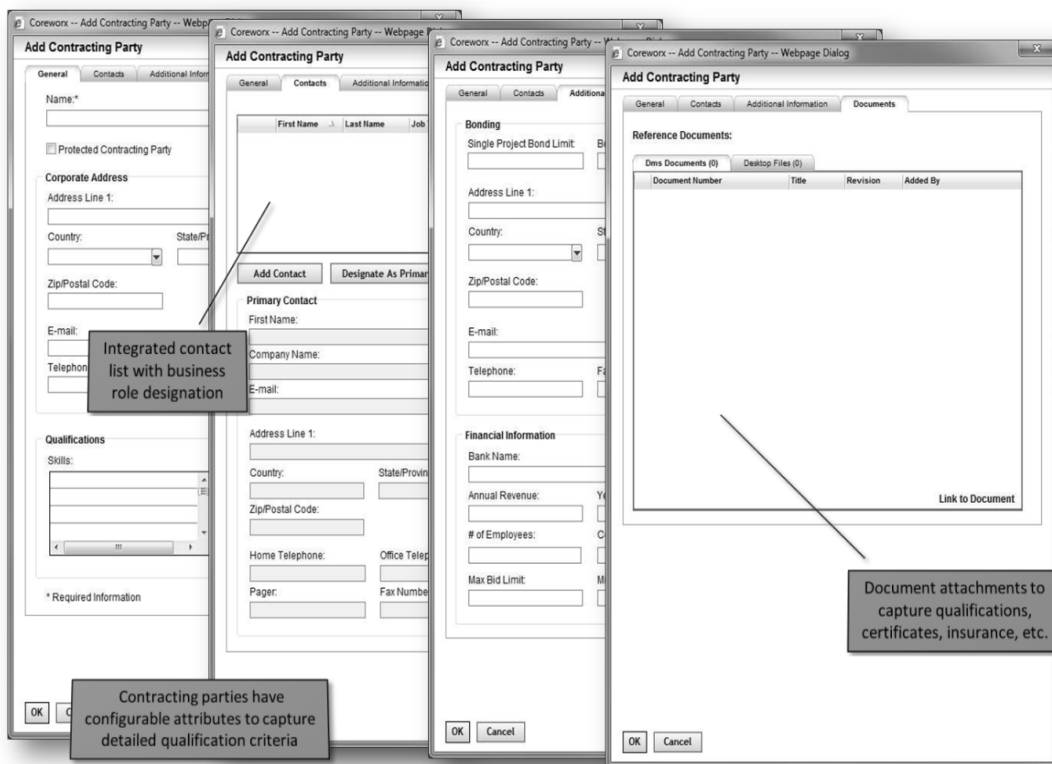


Figure 5-2: Snapshot of the Production of a List of Potential Contractors Using the Developed System

Significant changes, learning, adaptation, and growth are inevitable when a construction value unit (CVU) is implemented. The evaluation of the contractor is a vital component of this system and is related to risk and risk management (Jaselskis and Russel, 1992; Russell et al., 1992; Kumaraswamy, 1997). During the bidding and negotiating process, selecting the best contractors with respect to the relevant CVUs is highly critical for the overall success of the entire project. To select the best

contractors for the CVUs and to prepare the most realistic and accurate bid proposals, the experts must be aware of all financial, technical, and general information about the packages. A number of converging studies and technical advances contribute to the ability of the proposed system to increase the feasibility of meeting this challenge; however, the method and perspective presented in this research differ from those of previously developed systems.

During the bidding process, a significant risk is ineffective partnership strength, which occurs when the relationships between managers (decision makers) and contractors are too personal: most decisions are affected by such connections. While this kind of personal selection practice has associated benefits, such as stability, mutual trust, and reduced transaction and search costs, it also entails problems. For the development of the system during this phase, a critical recommendation is the avoidance of any unsystematic tendencies and reliance, instead, on a systematic method for designating a contractor. However, the experts ultimately make the final choices, and the system can only approach the ideal optimal decisions.

The system developed in this research randomly generates a feasible option set of CVPs and then ranks them with respect to their assigned score. The feasible option set created by the system is presented to decision makers (project team managers) as a creativity set. This part of the system was created based on interviews with a number of scholars and with construction project managers who are in charge of numerous mega projects in North America and Southwest Asia. A landscaping job for a residential backyard can serve as an example. A construction engineer undertaking such a project may initially think of 10 feasible options. However, once friends and experts respond to a request for ideas, a number of options may surface that have not previously even been imagined. A comparison of this simple example with a mega construction project reveals the complexity of this decision-making process and demonstrates why experts would support the development of the proposed system. Obviously, a system can never make a final selection and should be considered as a creativity tool that generates feasible option sets. The proposed tool should be viewed as a guide for improving the efficiency of the bidding decision process by decreasing the time required for making a decision and by generating options that may not normally be considered during this process.

The selection of the best contractor for each job influences not only the success of the construction project but also the quality of the results produced by any model based on those decisions as input. In particular, during the bidding process, the optimal selection of the contractors is vital because it results in an accurate and realistic bid proposal for each CVP. During this phase decisions are focused

at the managerial level, the point at which public officials and designated decision makers have the power to accept or reject a contractor for a specific construction value unit (CVU) based on management-level considerations. As presented in the following sections, the algorithm developed for the new system incorporates these factors.

5.1 System Algorithm

A randomization algorithm is used in the system developed in this research as a means of presenting to the owner of the project a series of possible distributions of value units within the value packages. The algorithm enables the tool to facilitate the contracting process significantly, because the options generated can be ranked according to their weighted score, and the top 20 of 1,000 arrangements can be displayed in descending order and then presented in a user-friendly Excel spreadsheet. If the project managers/experts involved in the bidding process are not satisfied with any of the options, they can simply run the tool again, which will generate a different set of combinations for them to view. The layout of the hierarchy and one possible combination of value packages is shown in Figure 5-3.

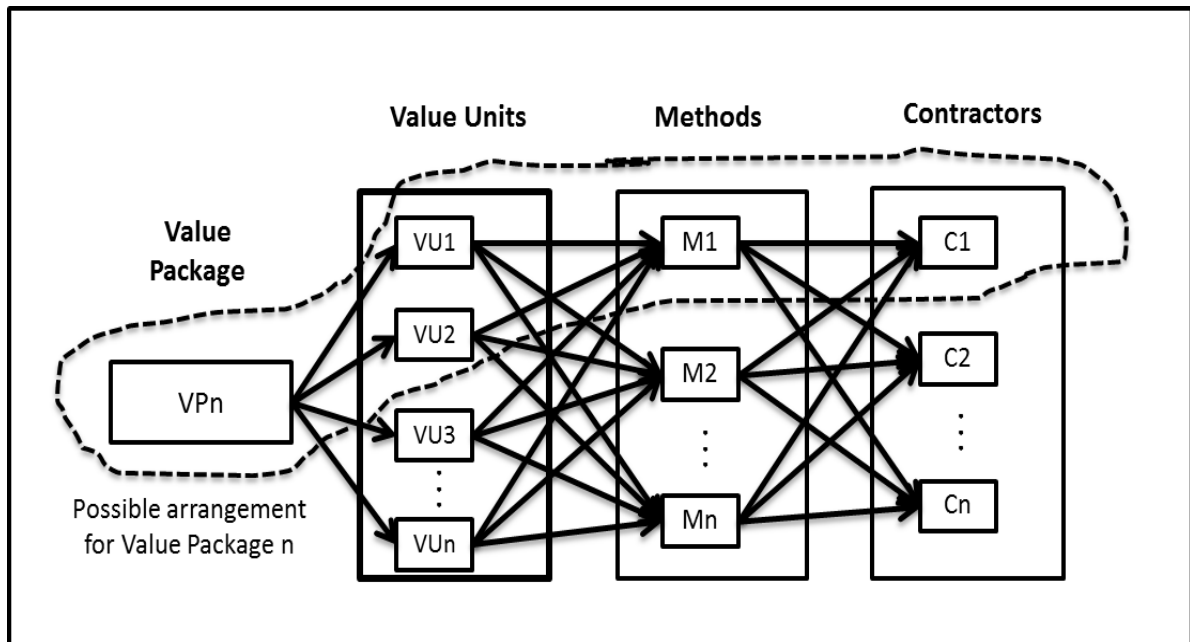


Figure 5-3: Value Unit Development Process

The MATLAB programming language was used to create the randomization tool (Appendix D). It allows a simple interaction with Microsoft Excel spreadsheets because it can extract and manipulate the data as well as maintain the indexing established within the spreadsheet. MATLAB also enables fast numerical computations; in a little over one second, one thousand different combinations can be generated for the site owner to view. Figure 5-4 shows the output for the variable “final-cell,” in which each row represents a different combination of the value packages.

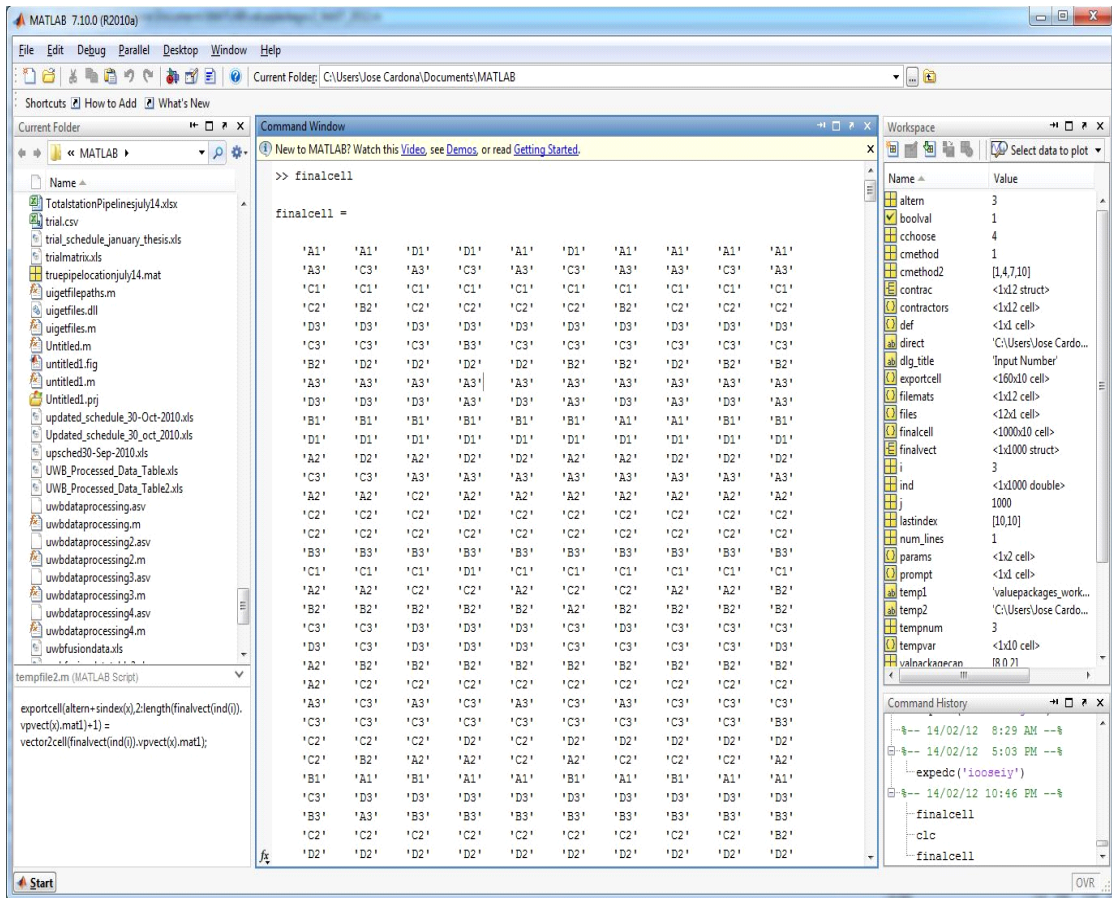


Figure 5-4: MATLAB Screen Capture

The algorithm starts by extracting the criteria matrices (described in the next section of this thesis) from the user-specified folder, which it detects the number of contractors potentially available for each value unit. The user is expected to input an objective evaluation for each criterion in the value package that is associated with an individual contractor. Each contractor and method must also have a separate criteria matrix, as shown in Figure 5-5.

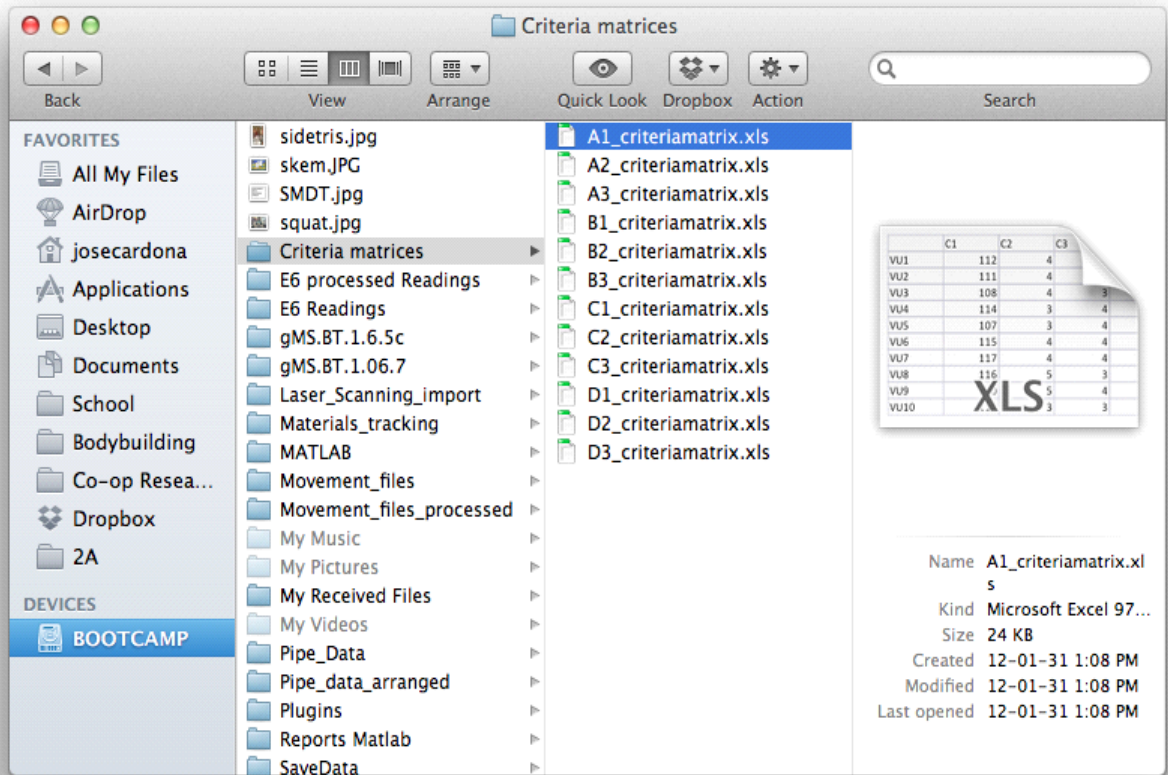


Figure 5-5: Snapshot of the Folder and File Formatting for Criteria Matrices

Each matrix is then normalized and multiplied by an established weighting vector. A vector containing the objective function values for each value unit is obtained for each contractor. The data are then stored within a variable in order to obtain a numerical measure of the proficiency of a contractor with regard to a specific value unit. The approach for calculating the score is detailed in the next section.

The randomization process begins with the generation of the quantity of value units per value package and the storage of that quantity within a variable. Next, the value packages are arbitrarily distributed so that the capacity of each value unit is filled. The user is then prompted to specify the number of methods available for all value units. For each value package, one method is selected at random. For

example, for piping activities two methods can be considered: weld-less connections and traditional welding systems. Lastly, a contractor is selected at random from the list of contractors who can perform the value unit using that method, and the entire combination is stored. This description covers a single iteration of the algorithm. The sequence of operations is looped one thousand times, with the results being stored in a variable and then exported as an Excel file. The layout of the algorithm is shown in Figure 5-6, and the score calculation process is discussed in the next section.

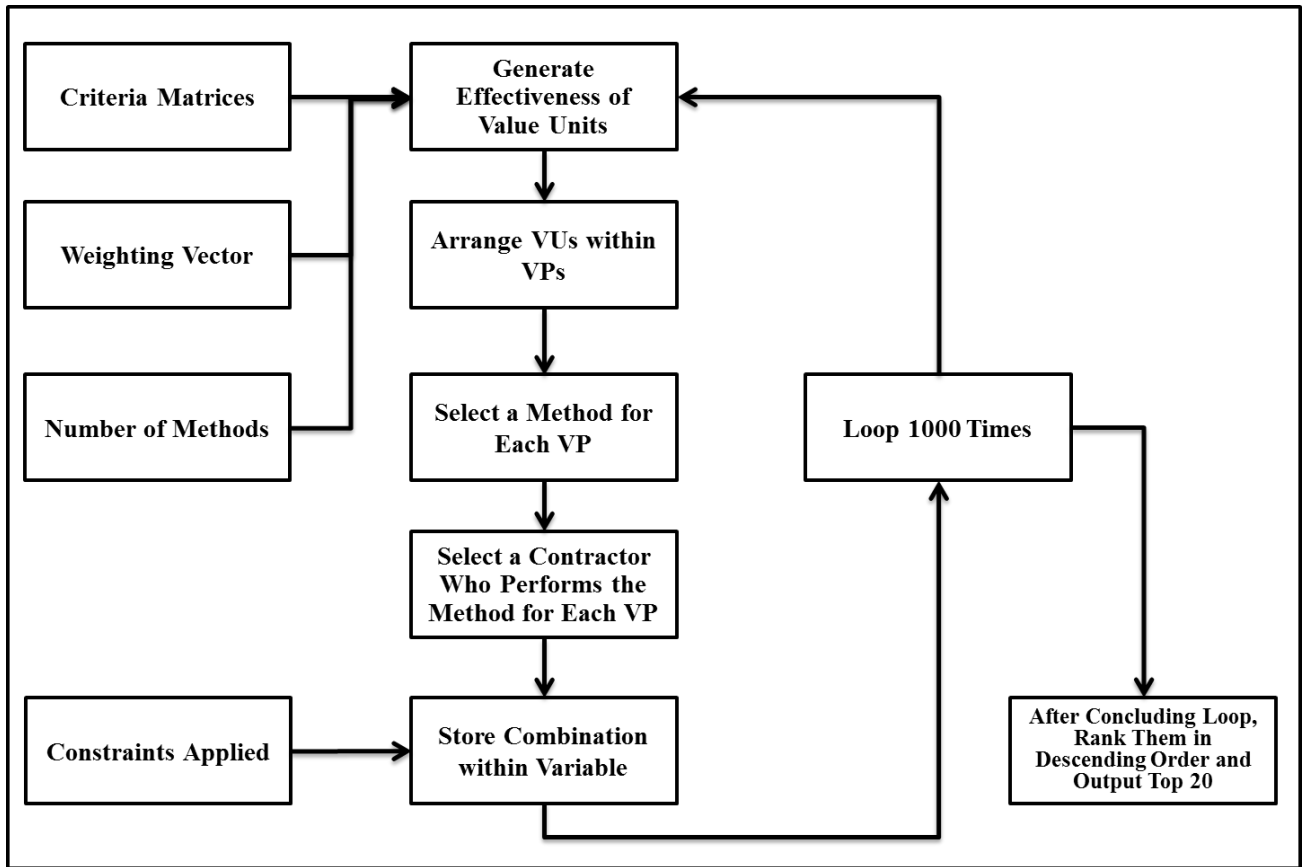


Figure 5-6: Flowchart of the Selection Process Algorithm

5.1.1 Value Unit Score Calculation

Because of the limited time intervals in the bidding process, simple but effective methods of contractor selection are important with respect to meeting the needs of the construction industry. Some of the existing methods and approaches can be complex and difficult to apply in practice. For this research, the Simple Additive Weighting (SAW) method was selected for the calculation of the score for each value unit in combination with its method and an assigned potential contractor.

The SAW approach is probably the best-known method of Multi-Attribute Decision Making (MADM). In the SAW approach, the overall score of an alternative is determined based on the weighted sum of all attribute values (Churchman and Ackoff ,1954; MacCrimmon, 1973; Hwang and Yoon,1981; Hipel, 1992, Chen and Klein,1997;Wenhui, 2004; Phuoc Nguyen and Boukhatem, 2008; Ravanshadnia, et al., 2010). The “ranking identification” problem in SAW takes effect especially when the attribute values of alternatives are very similar (Tran and Boukhatem, 2008). The score for each alternative is obtained through the addition of the normalized contributions of each value multiplied by the assigned importance weight. The selected interface is then as follows:

$$A^* = \left\{ A_i \left| \max \sum_j w_j \times r_{ij} \right. \right\} \quad (1)$$

The main steps in the SAW decision-making approach are as follows: normalize a decision matrix and calculate the weight of the attributes using the entropy weight method in order to calculate the function F. For these steps, we assume that $a_{ij} \neq 0$.

Normalized Decision Matrix

With the SAW method, m alternatives (options) and n attributes/criteria are assumed, and a score is assigned for each option with respect to each criterion. If option i has a score of x_{ij} with respect to criterion j, then a matrix X is an m×n matrix (decision-matrix, Figure 5-7). It should be noted that the project management team must adjust the attributes to correspond to the requirements for each value unit within the project class and specifications because the attributes selected should have a direct effect on the performance of the VU.

	C1	C2	. . .	Cn
A1	x11	x12	. . .	x1n
A2	x21	x22	. . .	x2n
.
.
.
Am	xm1	xm2	. . .	xmn

Figure 5-7: Structure of the Alternative Decision Matrix

A_i is a possible CVU (alternative i) in a group of potential CVUs from which decision makers must choose a specific CVU, and C_j is criterion j based on which alternative performances are measured. The variable x_{ij} is the rating of alternative A_i with respect to criterion C_j . The evaluation attributes are selected based on consideration of the objectives and interests of the project team. The partial attributes/criteria (C_1, \dots, C_j) can be changed from one project to another in order to accommodate the one-off nature of the construction industry. However, some important criteria for selecting the best contractor are employed in most construction projects (Jaselskis and Ashley, 1991; Ledbetter, 1994; Herbsman, 1995; Herbsman, 1997; Working Group, 1997; Hatush, 1998; Mahdi et al., 2002; O'Connor et al., 2004; Singh and Tiong, 2006). The attributes for developing the decision matrix in this study include but are not limited to the following:

1. Price (potential bid price)
2. Financial status, which is usually assessed based on ratio analysis and an examination of bank references, credit references, and turnover history (Holt et al., 1994)
3. Number of years in business: appropriateness of experience and performance of work of the same general type and on a scale not less than 50 % of the amount of the proposed contract
4. Adequacy of the supply chain with respect to appropriate and expeditious support for the work
5. Previous performance: type and scale of projects completed in the past three to five years, quality of work in past projects, percentage of previous work completed on schedule, and quality of relationships with past project owners (Hatush and Skitmore, 1997)
6. Project management organization: availability, qualification, and level of experience of project manager and professional technical staff; project management structure
7. Technical expertise: appropriateness of technical ability
8. Familiarity with local working culture

9. Relationships: relations with subcontractors, industrial relations, occupational health and safety, and claims and dispute history

10. Ability to perform and manage a variety of construction value units

After the decision matrix is established, the various attribute dimensions must be transformed into non-dimensional attributes, which allows comparisons across criteria. The raw data are normalized to eliminate anomalies with respect to differing measurement units and scales. In general, the results produced by the SAW method do not depend on the normalization technique. The scores or data are normalized with the use of one of the following alternative procedures:

1. Vectorial normalization: This normalization uses one of the formulae

$$\text{Equation 2: } n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^m x_{ij}^2}}, \text{ or } n_{ij} = \frac{x_{ij}}{\sum_{j=1}^m x_{ij}}, j = 1, \dots, m, i = 1, \dots, n.$$

2. Normalization by linear transformations: For the maximum criterion J , the formula used is

$$\text{Equation 3: } n_{ij} = \frac{x_{ij}}{x_i^{\max}}, x_i^{\max} = \max_{1 \leq j \leq m} x_{ij},$$

and for the minimum criterion J , the formula used is

$$\text{Equation 4: } n_{ij} = 1 - \frac{x_{ij}}{x_i^{\max}}.$$

One can also use the following normalization formulae for a maximum criterion and for a minimum criterion, respectively:

$$\text{Equation 5: } n_{ij} = \frac{x_i^{\max} - x_{ij}}{x_i^{\max} - x_i^{\min}}, x_i^{\min} = \min_j x_{ij}$$

$$\text{Equation 6: } n_{ij} = \frac{x_{ij} - x_i^{\min}}{x_i^{\max} - x_i^{\min}}$$

3. Normalization by alternative linear transformations: This normalization uses the following formulae for a maximum criterion and for a minimum criterion, respectively:

Equation 7:
$$n_{ij} = \frac{x_{ij}}{x_i^{\max}}$$

Equation 8:
$$n_{ij} = \frac{x_i^{\min}}{x_{ij}}$$

where n_{ij} are normalized values of decision matrix elements. When the normalization is corrected, it should also be noted that $0 \leq n_{ij} \leq 1$.

Calculation of the Weight of the Attributes Using the Entropy Weight Method

Shannon's entropy method is one approach that was applied in this study in order to obtain a weight for each criterion when a suitable weight cannot be obtained based on the preferences. After all the evaluation index factors have been confirmed, the entropy weight is calculated according to the normalized decision matrix. The original procedure for Shannon's entropy method can be expressed as a series of steps (Shannon, 1948):

Step 1) Compute entropy h_i as

Equation 9:
$$h_i = -h_0 \sum_{j=1}^m p_{ij} \cdot \ln p_{ij}, \quad i = 1, \dots, n$$
, where h_0 is the entropy constant and is equal to $(\ln m)^{-1}$, and $p_{ij} \cdot \ln p_{ij}$ is defined as 0 if $p_{ij} = 0$.

Step 2) Set $d_i = 1 - h_i, \quad i = 1, \dots, n$ as the degree of diversification.

Step 3) Set (Equation 10: $w_i = \frac{d_i}{\sum_{s=1}^n d_s}, i = 1, \dots, n$) as the degree of importance of attribute I.

Step 4) If there is a weight vector $A = a_1, \dots, a_m$ based on a historical database or on the presumption of experts, the entropy weight is then the comprehensive weight matched with the i th index factor, as follows:

Equation 1: $w'_i = \frac{a_i \times w_i}{\sum_{i=1}^m a_i \times w_i}, i = 1, \dots, m$

Step 5) Set $d_i = 1 - h_i, i = 1, \dots, n$ as the degree of diversification.

Step 6) Set (Equation 2: $w_i = \frac{d_i}{\sum_{i=1}^n d_i}, i = 1, \dots, n$) as the degree of importance of attributes i.

Step 7) If there is a weight vector $A = a_1, \dots, a_m$ based on a historical database or on the presumption of experts, the entropy weight is then the comprehensive weight matched with the ith index factor, as follows:

Equation 3: $w'_i = \frac{a_i \times w_i}{\sum_{i=1}^m a_i \times w_i}, i = 1, \dots, m$, Thus, the comprehensive weight vector is:

$$w' = (w'_1, w'_2, \dots, w'_i)$$

Calculation of the Function F

A is the finite set of alternatives. The final score of each alternative is calculated as follows, and they are then ranked.

$$\text{Equation 4: } f_i = f(A_i) = \frac{\sum_{j=1}^m w_j r_{ij}}{\sum_{j=1}^m w_j}, 1 \leq i \leq n, \text{ If } \sum_{j=1}^m w_j = 1, \text{ then } f_i = f(A_i) = \sum_{j=1}^m w_j r_{ij}$$

The case studies presented in the following sections illustrate in detail how value packages are developed.

5.2 Case Study 1: Pipe Installation at the Portland Energy Center

The Portland Energy Centre is a recently constructed thermal power plant located on the waterfront near downtown Toronto, Ontario, Canada. The plant will be able to generate as much as 550 MW of electricity from two turbines. The project was large, with a very tight schedule. Taking into account the dissimilarity of most value packages with respect to scope, size, and other factors associated with the nature of the work, the project encompassed close to 2000 construction packages. The research was focused on the massive piping system, whose complex piping work was split into more than 10 (value units), each about 20 ft wide, 115 ft long, and 70 ft high. The possible methods of creating each module included modular (complete modules), prefabricated (small module), and stick-build (on-site). The names of the contractors and all details associated with the contracts have been kept confidential and may not be made public. Capital letters have therefore been used as anonymous designations for contractors. All bidding documents for this project, including the drawings, designs, plans, specifications, models, reports, and other documents are also strictly confidential, and in accordance with the terms of the confidentiality agreement, publication is not permitted.

The initial investigation included the examination of several factors, for which the process was typical of most such projects: the stages, types, and places of fabrication. The on-site fabrication equipment consisted of mainly light-duty tools that were considered to be lower in efficiency than the heavy-duty equipment located in the fab-shop and at the assembly site (Figure 5-8). The time consumed for fabrication on the site was generally three times greater than that required in the fab-shop for the same unit. The operating environment in the fab-shop or at the assembly site was superior to that in the power building. Power generation structures are often not conducive to smooth operational access for crews and equipment. However, when units are built at an off-site assembly site, a crane can work around the module, and crews and equipment have easy access.

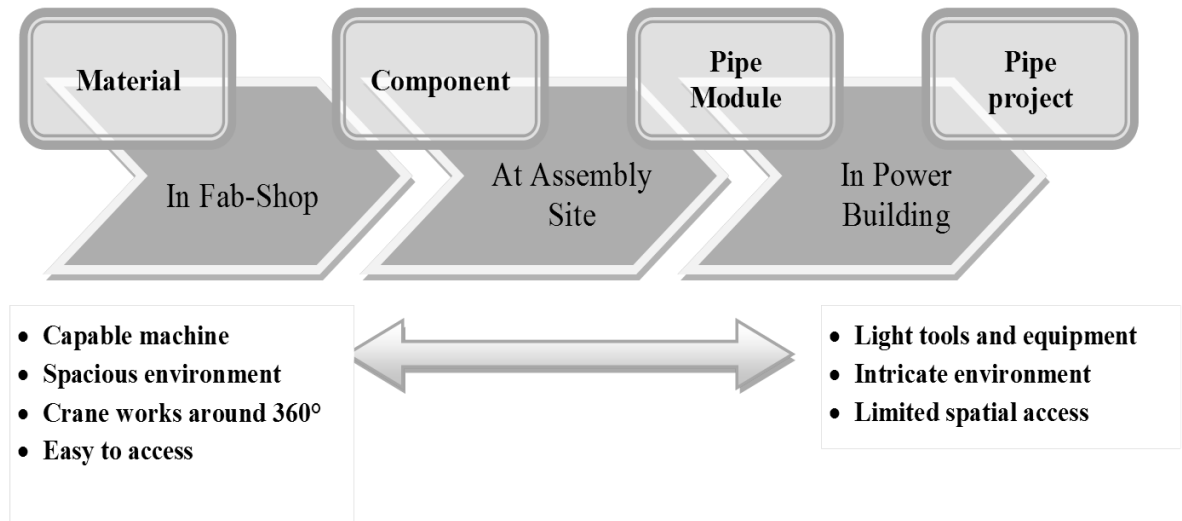


Figure 5-8: Comparison of Operating Environments

With consideration of the above issues, three methods were defined for each piping value unit: modular, prefabricated, and stick-build. In this project, these three methods can be considered for each piping module CVU (construction value unit). The pipe module shown in the photograph in Figure 5-10 was part of the project and included racks, pipes, hangers, and valves. Figure 5-9 shows a value chain for building such a pipe module. Experts and planners can analyze and simulate the project by developing different alternatives, taking methods, stages, and places of fabrication into account. Each alternative can then be a potential value unit. For example, the colored lines in Figure 5.9 show one potential value unit; multiple color-line areas can be created as alternative possible value units. However, it would be an ideal practice if any stage (that adds any value) is considered as a value unit. For example, Fab-Shop 1, Paint-Shop 1, and Assembly in Module-Yard are potential value units. This ideal approach is challenging to implement in practice, although it is feasible, accurate and efficient.

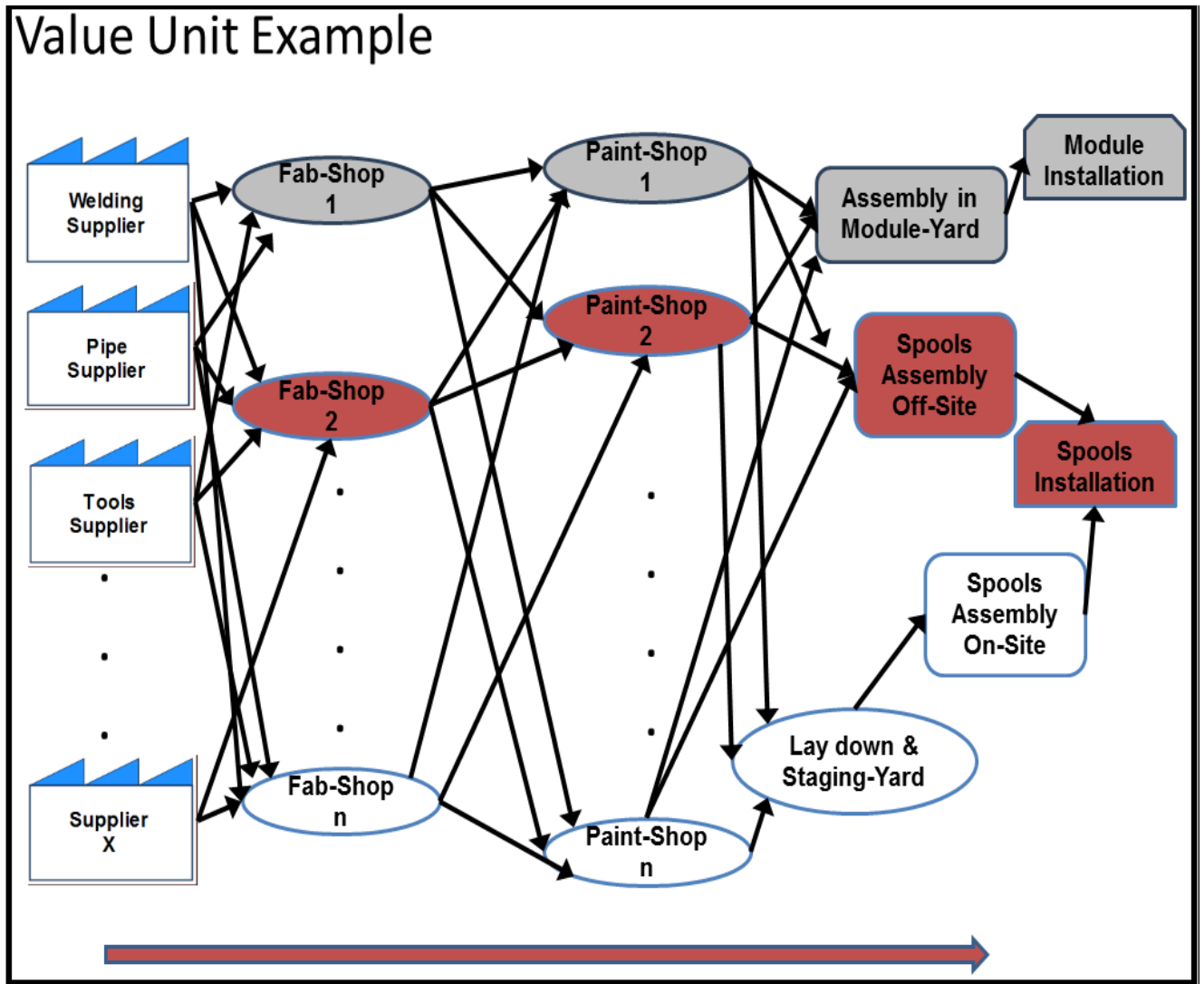


Figure 5-9: Example of the Value Unit Development Process



Figure 5-10: Example of the Value Unit: Piping Module

For site work, the predominant causes of delay are design changes, poor labor productivity, bad weather, and inadequate planning. Many of these delays can be mitigated through the use of staged fabrication methods, which help increase labor productivity and reduce both the amount of materials stockpiled on-site and the manpower required to manage them. Prefabrication, preassembly, modularization, and off-site fabrication (PPMOF) decisions are complex and involve many factors which can be evaluated using existing tools (Haas, 2000). When such tools have been used by project experts, the results can inform the CVU performance estimates. Modules and preassemblies need special consideration because of the level of design and the amount of materials required. Some projects can involve hundreds of modules, which must be reflected in the system. In the future, the lack of skilled workers and the inability to meet compressed schedules because of the time required to complete the entire process on-site will encourage the extensive adoption and utilization of staged fabrication systems. However, when value units are developed, all methods must be considered, and in some circumstances, a traditional method may prove to be the best option.

Value units are mutually exclusive. Depending on the size, complexity, and number of value units involved, the set of feasible CVUs can be acquired either manually or through an automated process. Developing value units requires that sufficient information be obtained from a number of experts at the very beginning of the project. This phase can be both time-consuming and costly. However, since most of the risks associated with a project are related to areas where interaction occurs between parties, the early recognition of important interfaces between packages and the identification of unqualified contractors will significantly help reduce the overall risk.

In this phase, “value” is assigned to each value unit through consideration of the scores assigned for the value unit providers as measured against the value packages. Value is considered to be the amount a desired value package is worth relative to other feasible value packages. The value is usually presented as lowering the cost. However, as mentioned in the previous section, several tangible (e.g., price and financial status of the CVUs) and intangible (e.g., familiarity of the value unit provider (VUP) with the local working culture) criteria must be assessed in order to determine the value of the work packages.

The set of feasible value packages with the best value is the optimal solution, one in which all the CVPs selected add up to the entire project, and each VUP cannot perform more than one value package. When computing 10 optimal solutions is impractical, the user must settle for a good (but not necessarily optimal) solution. This part of the CVPS helps decision makers look at a variety of combinations of value units more effectively, efficiently, and objectively.

This project involved approximately 1000 value units. Initially, we ran the system only for piping modules, so a trial run of the algorithm was implemented for a scenario of 10 value units, all of which can be performed by three contractors (VUPs) using three different methods. For this example, the criteria matrix generated (Figure 5-10) consists of five criteria. The layout of the input data is shown in Table 1.

Table 1: Data Input Layout for the Trial

Number of Piping Module (unit)	10
Number of Contractors	3
Number of Methods	3
Number of Criteria	5
Possible Options	3,486,784,401

As explained, the proposed system uses the information from Table 1 to run the decision-making process. The criteria matrices were therefore set up so that Contractor A was best suited for VUs 1-5, Contractor B was best suited for VUs 6-8, and Contractor CD (contractor C with contractor D) was best suited for VUs 9 and 10. The objective was to evaluate whether the software would generate the desired combination within a set number of loop iterations. The output of the algorithm provides the 20 best alternatives for the evaluated objective function values, arranged in descending order. Figure 5.10 shows the top three alternatives: for alternative 1, contractor B with method 2 will perform VP1, including VU6, VU8, and VU9; for alternative 2, contractors C and D with method 2 will perform VP2 (VU7 and VU10); and for alternative 3, contractor A with method 2 will perform VP3 (VU1, VU2, VU3, VU4, and VU5).

Alternatives	Value Package	Contractor	Methods	Value Units
Alt. 1	VP1	B	2	VU9, VU6, VU8
	VP2	CD	2	VU10, VU7
	VP3	A	2	VU1, VU2, VU4, VU5, VU3
Alt. 2	VP1	A	1	VU2, VU5, VU4, VU3, VU1
	VP2	CD	1	VU10, VU8, VU9, VU7, VU6
Alt. 3	VP1	CD	3	VU7, VU9, VU8, VU2, VU10, VU6
	VP2	A	3	VU3, VU5, VU4, VU1

Figure 5-11: Top Three Alternatives for Case Study 1 as Output by the Randomization Tool

In reality, defining value units and the selection of the best value package providers involves a number of constraints and limitations, including the availability of the value unit providers (contractors) given the project's requirements, the influence of the Canadian Construction Workers' Union (CCWU) and other unions, governmental issues for mega projects, the capacity of the VUPs, the necessity of avoiding the placing of a VUP in a monopoly position, and inconsistency in performance with respect to different VUPs. As mentioned, a set of feasible value packages is comprised of a unique aggregation of value units that sums to the total value added that is required in order to complete the scope of work under consideration. Stated simply, the work is split into value units, and the value units then merge into a set of feasible value packages that incorporate a variety of alternatives for performing the same tasks. The set of feasible value packages with the best total value is then the optimal solution: one in which all the VUPs selected add up to the entire project and each

VUP cannot perform more than one value package. When it is impractical to compute an optimal solution, the user must settle for a good (but not necessarily optimal) solution. The final decision is based on intangibles and judgment.

This part of the CVPS helps the decision makers consider a variety of combinations of value units more effectively, efficiently, and objectively. For this optimization “near optimization”, the objective function is the max project scores value, with the following as some of the suggested constraints:

1. A contractor is not used more than once for any one value package.
2. The production capacity of the contractors must not be exceeded.
3. A VUP must not be placed in a monopoly position.
4. The contractor must be available for a specific VU.

During the Portland Energy Centre pipe installation project, although Contractor A was the best VUP to run pipe for the component fabrication and module assembly, that contractor was assigned for only five pipe modules. The other five modules were given to Contractor B and another VUP. While the bidding information for the project was and still is confidential, the results show that numerous factors are involved in the making of such decisions. These factors can be considered as the constraints in the decision-making process in the developed system. If the actual bidding contracts are compared with the output of the system, alternative 1 matches exactly the actual decision. However, the decision is always made by experts rather than by a system, and we therefore cannot expect that the initial running of the system should produce the optimal solution.

5.3 Case Study 2: Northland Power Spy Hill Generating Station

The Spy Hill Generating Station is a 100 megawatt (MW) gas-fired, simple cycle power generation facility located in Saskatchewan and owned by Northland Power Inc. (\$700 million base-load power plant). Construction started on the project in 2009 (Figure 5-12). The facility is being constructed through a joint venture between two Canadian companies. The relevant scope of work for this research is the installation and furnishing of two glycol water heaters (turbines) and associated accessories, which are considered to be two value packages. The turbines were installed on a massive concrete pad, 6 m wide, 23 m long, and 1.5 m thick. The project included approximately 300 value packages; however, this research concentrated on two significant and strategic modules.



Figure 5-12: Northland Power Spy Hill Generating Station Project

Each of these two value packages (subprojects) was broken down into seven value units: (1) thermal fluid heating system, (2) complete skid mounting, (3) mag drive pump, (4) burner front enclosure, (5) burner house, (6) pump skid pipe insulation, and (7) surface preparation to meet SSPC – SP6. We used the original names of the value units, although these names do not provide a clear description of the scope of the job associated with each value unit. Figure 5-13 shows sample parts of these value units.

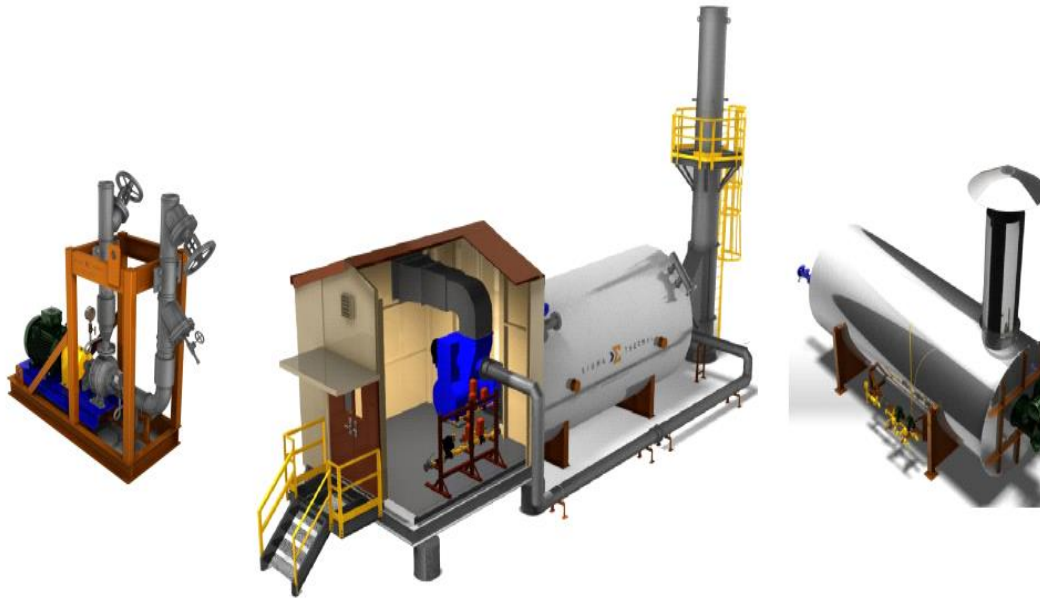


Figure 5-13: Sections of the Spy Hill Generating Station

Due to issues of confidentiality, the entire specifics of the data acquired for this project are not available for publication. This project involved a number of activities and requirements, including drawings and engineering; transportation; electrical enclosure assemblies; piping/tubing; welding (welding of carbon, low alloy, and stainless structural steel); project- and country-specific requirements; and control design and equipment. A spare parts estimate should be also provided because it would supply desirable assistance during the operational phase. Actual spare parts were selected during the engineering phase of the project in order to ensure that they comply with the specifications.

An evaluation project team of seven people, who are frequently involved in the contract management process, selected the main criteria for this project. Five main criteria were considered in this study, four of which are quantitative, and one of which has a qualitative value: (1) cost, (2) time, (3) field service and engineering rates, (4) experience, and (5) the financial stability of the contractor. As mentioned in section 5.1, the criteria selection and the provision of the criteria weight vector are the strategic input for the developed system.

The criteria weight vector describes the degree to which different alternatives approach one another with respect to a specific criterion. Based on the nature of the project and the opinion of the experts,

the weight vector (Wj) calculated for this project is [(cost) 0.4, (time) 0.2, (field service & engineering rates) 0.1, (experience) 0.2, (financial stability of the contractor) 0.1]. After “cost,” “time” is the most important criterion for this project: it is a material provision, and the contractor acknowledges that the owner relies on the contractor's timely performance in completing the value unit as scheduled in the bid document (section 5.2). The contractor should therefore provide a detailed baseline schedule that encompasses all activities associated with the value unit and also needs to provide work progress reports for the value unit, as the owner may request from time to time. If the owner notifies the contractor in writing that the work is not progressing as scheduled, the contractor must implement appropriate corrective measures immediately after receipt of the owner's notice and will be solely responsible for any costs incurred in order to implement corrective measures.

The system was run twice for this project: first without any constraints and then with a constraint. The result of the first run shows that Contractor A1 could be awarded the contract for VP2, including four value units: thermal fluid heating system, complete skid mounting, mag drive pump, pump skid pipe insulation, and surface preparation to meet SSPC – SP6. Contractor B1 may be awarded the contract for VP1, including two value units: burner house and burner front enclosure. Contractor C1 would be awarded the contract for VP3, including one value unit: mag drive pump. The number one subscript after A, B, and C indicate that only one method was considered for each value unit in this part of the project (Figure 5-14).

Because the partners in the joint venture (owner) would like to deal with one contractor for this specific project, the system should be run with this constraint. The bid evaluation results for the glycol water heaters show that contractor A is the best contractor. Contractor A was therefore awarded the contract based on their ability to comply with the technical specification, to offer the lowest cost, and to meet the July 2010 schedule.

Alt_1				
VP1	Burner House B1	Burner Front Enclosure B1		
VP2	Thermal Fluid Heating System A1	Option to meet SSPC – SP6 Surface Prep. A1	Complete Skid Mounting A1	Pump Skid Pipe Insulation A1
VP3	Mag Drive Pump C1			
Alt_2				
VP1	Pump Skid Pipe Insulation C1	Mag Drive Pump C1		
VP2	Thermal Fluid Heating System A1	Complete Skid Mounting A1		
VP3	Option to meet SSPC – SP6 Surface Prep. B1	Burner Front Enclosure B1	Burner House B1	
Alt_3				
VP1	Burner House B1			
VP2	Option to meet SSPC – SP6 Surface Prep. A1	Complete Skid Mounting A1	Thermal Fluid Heating System A1	
VP3	Burner Front Enclosure C1	Pump Skid Pipe Insulation C1	Mag Drive Pump C1	

Figure 5-14: Top Three Alternatives for Case Study 2 as Output by the Randomization Tool

It should be noted that this research included proprietary information from the following categories: quotation pricing (supplemental product pricing tables and equipment pricing), technical documents required with the quotation, technical services (field service), delivery and shipments, subcontracting, the schedule, a business interruption plan, exceptions to the request for quotation (RFQ), payment terms, letters of credit (from an approved bank), submittals, agreements, contractor's representations and status, invoicing and payment, lists of materials, an intellectual property contract, off-site storage agreements, etc. The process of extracting the required data and information from these documents, including hundreds of papers and tens of Excel spreadsheets, took more than 150 working hours, which should be added to the time allotted for normal bidding process activities such as correspondence, contacting preliminary (potential) bidders, and bid clarification. If an owner is willing to reduce the time needed for the contract management process and to increase future

accuracy, we therefore suggest that a comprehensive database and strongly defined workflows for the bidding process be available.

5.4 Summary

Value packaging constitutes a new modeling paradigm especially suited for the complex and dynamic processes in a mega construction project. It is based on a set of value packages that is an optimized aggregation of value units. Developing value packages requires the early collaboration of the architect, the contractors, and the other stakeholders in the project, because the information stored in the historical database and the knowledge provided by specialists and experts are of great value during this process.

Decisions made during the bidding process are concentrated at the managerial level, the point at which public officials and designated decision makers have the power to accept or reject a contractor for a specific CVP based on management-level considerations. However, the proposed system enhances efficiency and performance for all contracting parties involved in construction projects. This system randomly generates a feasible option set of CVUs and then ranks them with respect to their assigned score. The feasible option set created by the system is then presented to decision makers (project team experts) as a creativity set. The proposed system should thus be considered a creativity tool to be used as a guide for improving the efficiency of the bidding decision process by decreasing the time required for a decision and by generating options which may not otherwise be identified. The system also creates an audit trail that can provide an explanation of the decisions. The results of the case studies and the opinions of experts indicate that the system will be a valuable tool for construction project management. The results also suggest that care should be taken to improve the CVPS in a systematic and logical way with the use of a benchmarking approach.

Chapter 6

Integrated Construction Materials Management

An Integrated Construction Materials Management (ICMM) sub system model is presented as one of the key elements of the ACSNM (Figure 6-1). Its core Bill of Material (BOM) management system is implemented and demonstrated with project case study data. The ICMM system has the potential to improve construction supply management processes and thereby lead to enhanced project performance. ICMM helps to ensure that selected materials are delivered to the construction site, in a manner that adheres to the project requirements such as price, lead-time, cash rebates, supplier performance, and preferred supplier early payments. The goal of developing the model was to reduce inventory and waste with respect to site materials, speed up delivery, and provide increased control of materials, all of which will decrease the cost of a construction project.

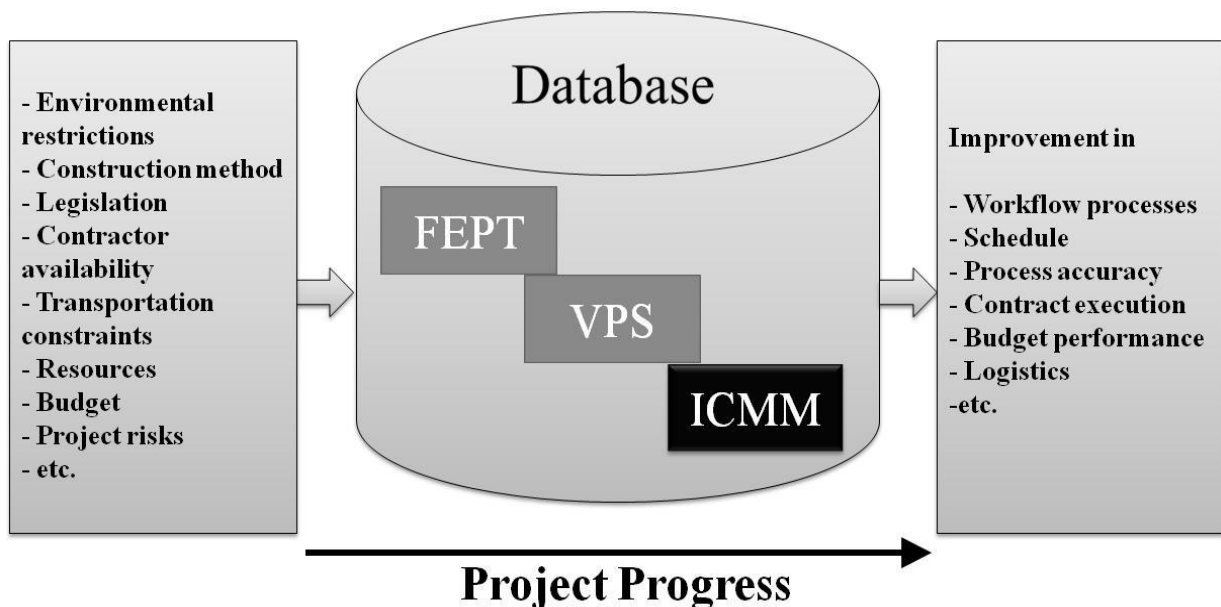


Figure 6-1: Integrated Construction Materials Management System and Other ACSNM Elements

The timely flow of materials is a central concern of construction project managers. The need for an integrated materials management system has been previously reviewed in this thesis, along with a discussion of the fundamental concepts related to construction materials management systems, including their benefits and deficiencies. The next section provides a detailed introduction to the critical role of the ICMM system as part of ACSNM.

6.1 ICCM System Development

In the ICMM system supply chain model, project management can view and forecast the anticipated arrival date of goods and are then presented with consistent and clear shipping documentation so that they can successfully complete the receiving process. The intend of the ICMM system is to control inventories in a consistent manner, with quick and efficient retrieval, and thus enable the material to be traced from receipt to release for use or return to the warehouse.

As mentioned previously, the construction value packaging system is a new modeling paradigm suited to the complex and dynamic processes inherent in a construction project. Once construction packages have been prepared, iterative improvements should occur during the subsequent phase. This process requires early collaboration between the construction project team, and other project stakeholders in the project because the knowledge provided by specialists and experts and the information stored in the historical database are extremely useful during this step. It should be noted that each construction package might contain more than one BOM; however, assigning only one BOM to a construction package is more desirable and easier to manage.

The ICMM system model created as part of this research was developed with the goal of eventually overcoming the manual and inefficient nature of the order process by enabling the identification of the appropriate BOM for which the total cost and primary product availability leads to the most cost-effective alternative for a particular product. The ICMM system is intended to be suitable for internal parties related to a project, such as the site management team, warehouses, the financial department, and the purchasing department as well as external parties, such as suppliers, fabricators, and transportation companies (Figure 6-2).

Figure 6-3 illustrates the components of the developed (ICMM) system model. It should be noted that the four of the main components of the system, including Labour Productivity and Cost, Planning and Control, Waste of Materials, and Workflow Management systems have been extensively explored by other researchers in the Construction domain, a summary of which was presented in section 2.5 of this thesis. Despite the development of these discrete systems, there is a strong demand in the construction industry for a system that is capable of providing the much needed integration between these various components. The BOM Management System model seeks to provide this integration through automating and optimizing the BOM management process. This model is presented in the next section.

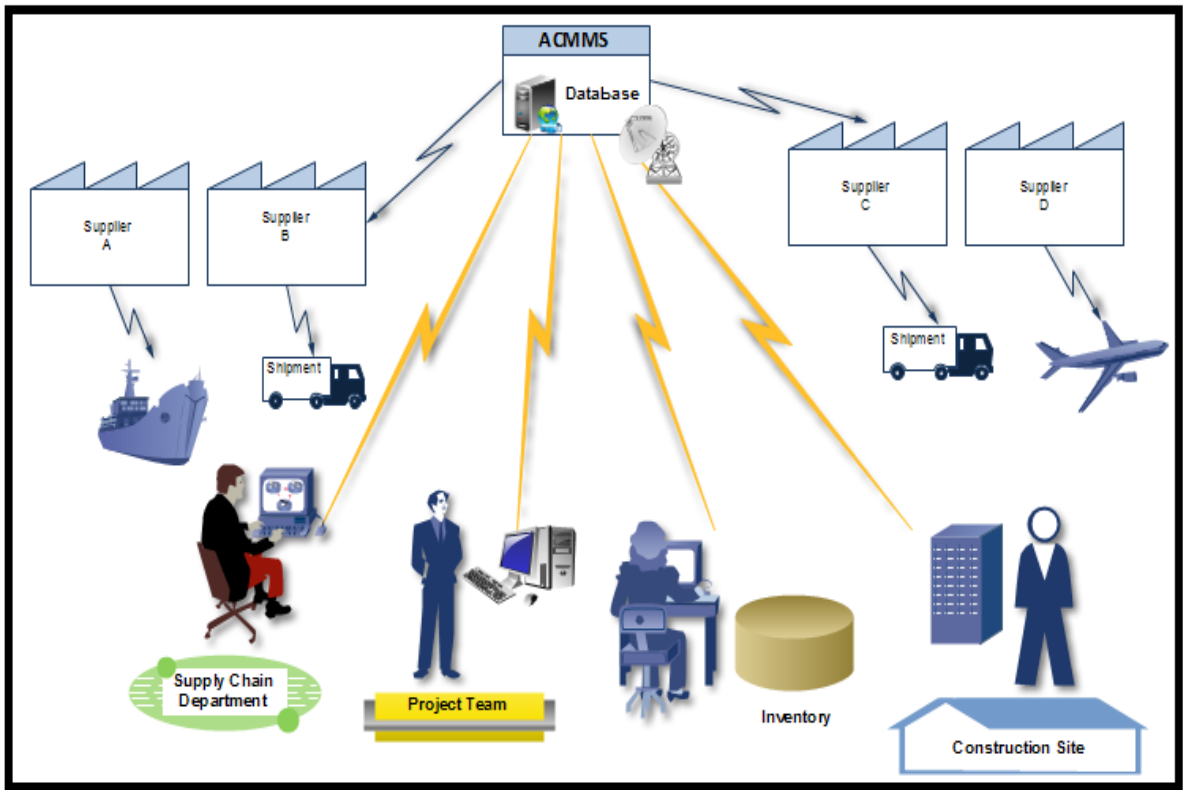


Figure 6-2: ICMM Database and its Interfaces

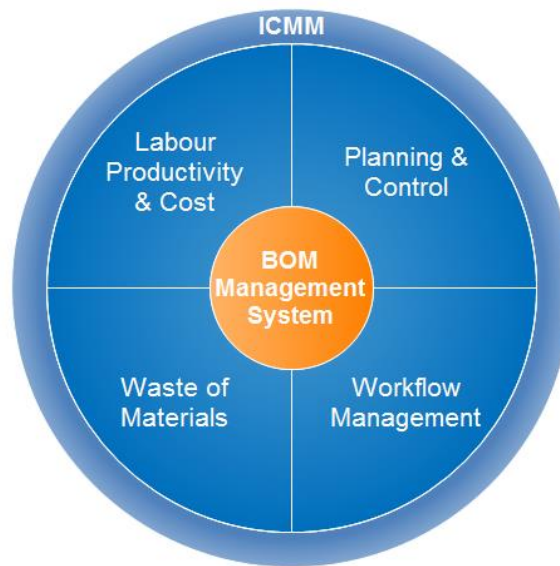


Figure 6-3: ICMM Components

6.2 BOM Management System

Personnel responsible for the supply chain determine requirements from a number of sources: materials may be identified by a request, a planning inquiry, a schedule review, or a restocking demand. The purchasing (supply chain) department can employ the developed system as a means of ensuring that timely and cost-effective procurement practices are followed and also that appropriate tasks are addressed proactively prior to procurement: determining shipping requirements and costs, creating and maintaining accurate BOMs, ensuring established warehouse procedures at the facility, ascertaining procurement requirements, determining whether materials are stocked, establishing a process for evaluating critical items, and setting up a procedure for verifying and coordinating the availability and cost of materials through monthly system updates.

An important functions of the ICMM system that has been implemented is software to generate the best possible procurement strategy for a particular product. For any large BOM, obtaining the most cost-effective and timely arrangement of primary products requires extensive labour. Both the quantities and prices of primary products in stock fluctuate over time and require constant updating. Manually updating these records as well as each individual corresponding BOM can prove extremely time-consuming. Time constraints can add to or subtract from the value to be derived from obtaining an item from a particular supplier, and experience with a specific product source and the possibility of bulk discounts can change product values. The ICMM system eliminates the necessity for manually updating an optimized BOM and takes into account both cost and time constraints along with any other criteria that should be evaluated.

6.2.1 BOM Optimization Process

The software that has been implemented for the BOM optimization process in the ICMM model processes all information relevant to the optimization of a BOM, including updated supplier information, generic BOM structures, and criteria weighting factors. An understanding of the system first requires clarification of some of the terminology and concepts: the generic BOM structure, the decision criteria, and the criteria weighting vector. A simplified workflow of the ICMM system is depicted in Figure 6-4.

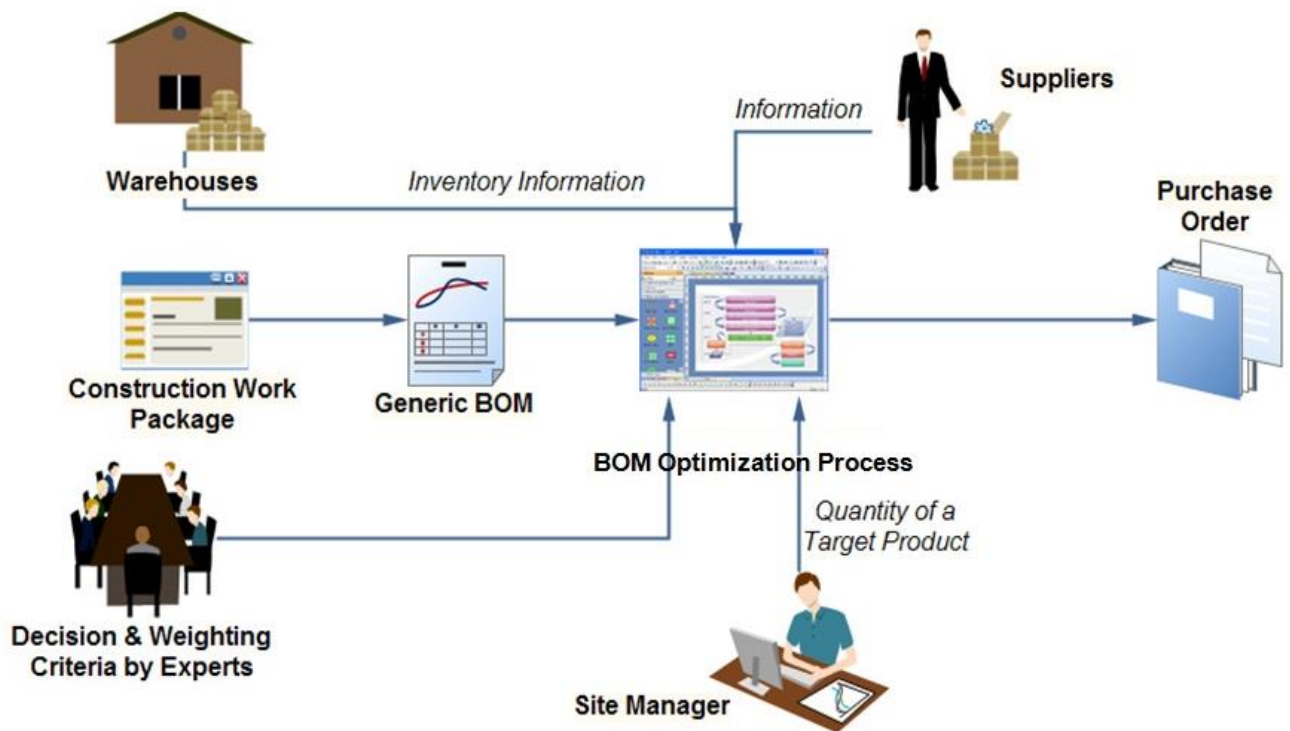


Figure 6-4: Simplified Workflow of the ICMM System

Figure 6-5 illustrates the flow and sources of required information for the ICMM system. As mentioned in the previous Chapter, the generic BOM (s) is one of the components of the each value package. The software initially checks the existing database information to check if there are at least three potential suppliers assigned to each item in the BOM. If “Yes” no further action is concerned, and if “No” the purchase department must update the list of potential suppliers and then assign no less than three suppliers to each item through market investigations.

The Criteria for evaluating potential suppliers and also the weight of individual criteria should be provided by the project management team prior to procurement process inception. A further requirement is the purchasing department order (initiated by site manager/supervisor), which indicates the required quantity of a target product. This number is multiplied by the amount listed for that product in the generic requisition order so that a final requisition order can be produced for the acquisition of materials for a specific project. A detailed discussion of this process is provided in subsequent sections.

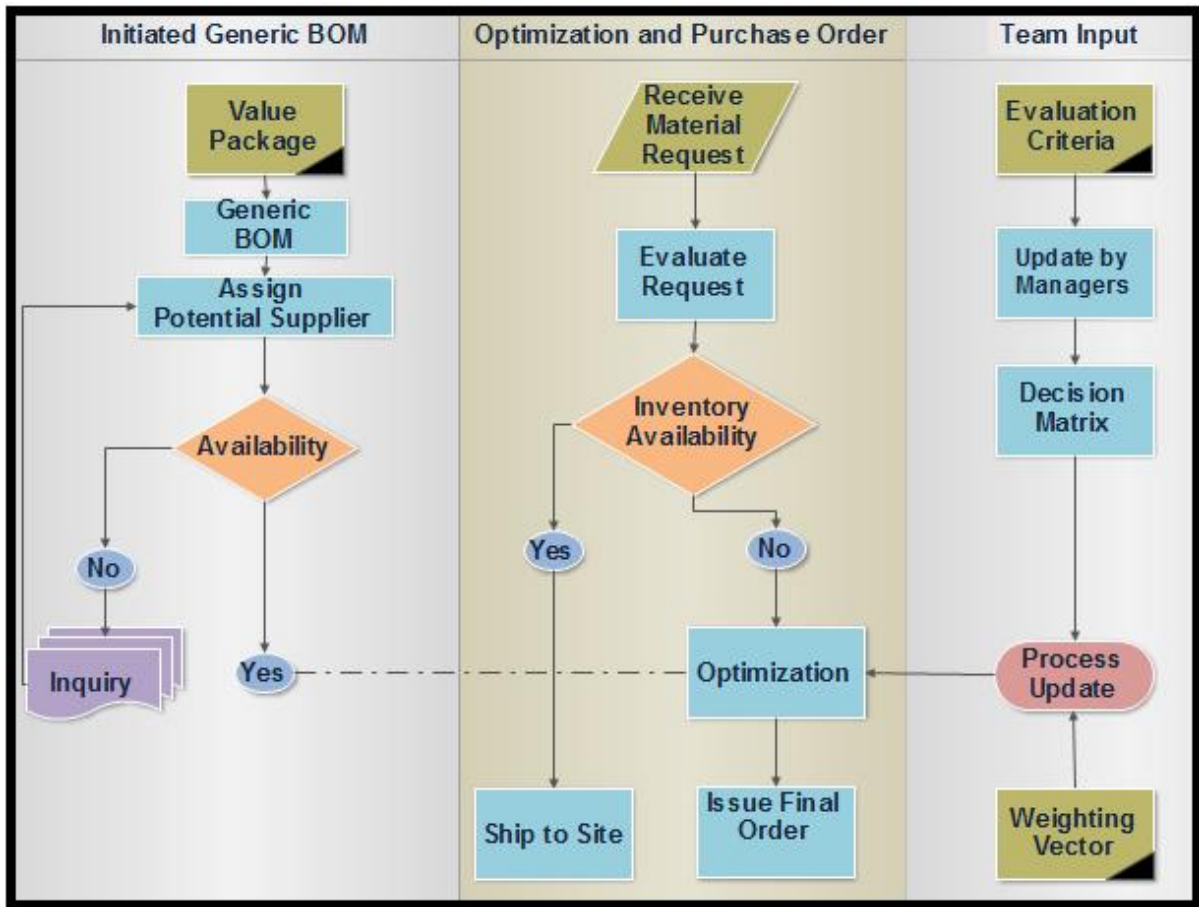


Figure 6-5: Simplified Workflow of the ICMM System

Figure 6-6 illustrates how the BOM optimization process operates for a single value package. The Simple Additive Weighting (SAW) method was used in the BOM optimization process. The details of the SAW method are presented in Section 5.1 of this thesis. Although the context in which this method is deployed in this chapter is different than that presented in Chapter 5, the underlying principles and methodology remain the same.

The first element which is involved in this process is the generic BOM. A generic BOM is designed during preparation of the construction packages as a means of describing the components for an explicit construction value package. A generic BOM contains the general description and quantity of each item in a final product, whose purchasing strategy should then be optimized based on some criteria such as availability, lead time, and cost taking the characteristics of the value package into

consideration. The decision matrix in Figure 6-6 shows how potential suppliers are evaluated against these criteria.

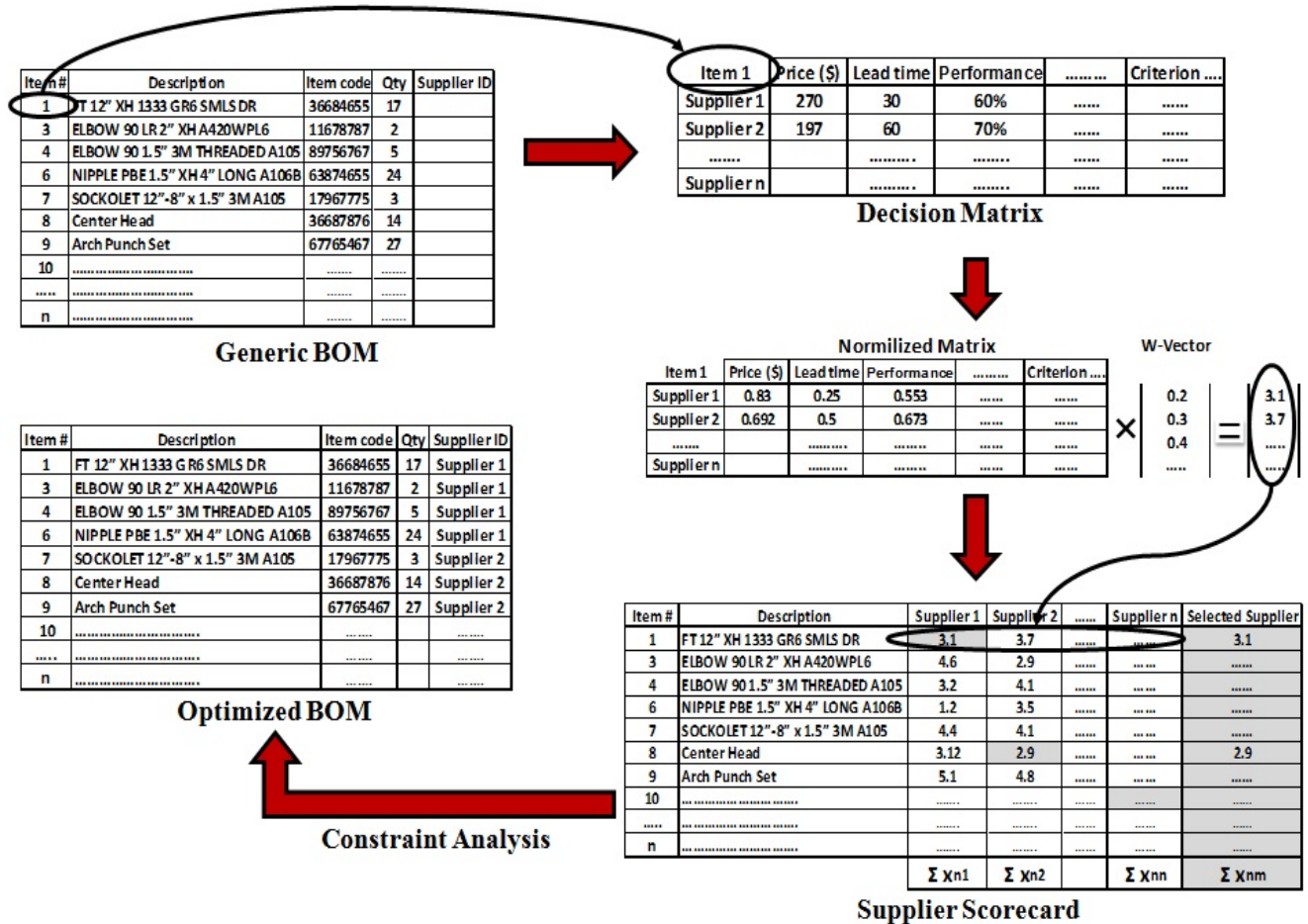


Figure 6-6: BOM Optimization Process

The decision matrix containing all the criteria for a particular item is taken from the supplier information database. The decision criteria are important elements of the developed system and can be changed from one project to another in order to accommodate the one-off nature of the construction industry. The selected criteria by the project team for the development of the decision matrix developed in this study are:

- price,
- lead time,

- supplier performance, and
- preferred supplier/early payment.

Once the decision matrix is established, the attribute dimensions must be transformed into non-dimensional attributes, which allows comparisons across all criteria. The raw data are normalized to eliminate anomalies with respect to differing measurement units and scales. The columns containing each criterion are then normalized. Each row indicates that an item originates from a specific supplier. The normalized criteria are multiplied by the weighting factors in order to produce a score for each of these rows that incorporate cost, time, and rating. The criteria weight vector determines the relative ranking of the alternatives. Based on the nature of the project and the opinion of the experts, the weight vector calculated for this study is [(1) price = 20 %; (2) lead time = 30 %; (3) supplier performance = 40 %; and (4) preferred supplier/early payment = 10 %].

After calculating the scores for each item against different potential suppliers, the supplier scorecard matrix is developed. The row index of this matrix that contains the lowest score for a particular item with the weighting factors taken into account indicates which supplier can provide the best alternative if there were no constraints applied to the system. However, for most work packages, there are a number of constraints applied to the material management and procurement systems. The constraints include avoiding sole-source positions by suppliers, managing the inventories, and supporting trusted suppliers.

When inventories and other constraints are applied, the items are then stored by the system for the optimized requisition order template for that particular value package. This process is looped for every item in each individual BOM. After the final requisition order for one unit of the BOM has been obtained, it is stored within the system. This process is repeated for each individual BOM stored in the database. It should be noted that for each BOM structure, every item is optimized individually.

6.3 ICMM System Implementation

The system is first launched, the system checks for an existing BOM database file to load (Appendix I). A sample of the GUI of the system implemented for BOM optimization appears in Figure 6-6. If no database file is detected, the system prompts the user to create a database by selecting a folder for each individual product one by one. For each folder selected, the system processes every BOM within that folder and stores the order lists for all primary products, along with the total cost of all products, taking into account the varying quantities for each separate BOM. After the database has been created

and detected, the system next creates a directory where all the optimized BOM selection files are stored and then switches to the optimization GUI, as depicted in Figure 6-7.



Figure 6-7: Optimization GUI for the BOM Optimization Process

The second GUI is comprised of a simple drop-down menu that lists every product within the database, an optimization button, and a database expansion button (Appendix H). To obtain an optimized selection of a BOM for a particular item from the value package, the user selects the product from the drop-down menu, presses the optimization button, and is then prompted to choose the quantity of the specific product desired. The system detects the BOM with the minimum cost and lead time from the database and outputs the order of primary products with the quantities adjusted based on the desired amount of the product input by the user.

The coded system is intended for use with a large BOM database so that any specific company can generate an order quickly and efficiently, without the requirement for manual browsing of BOMs and a lengthy selection process. With the ICMM system, most of the detailed record keeping and updates are automated, and project managers are notified about purchasing requirements. A current limitation of the system is the necessity of obtaining a common unit for both cost and lead time, input that is required for the system to produce an overall score for each BOM and thus to facilitate the optimization process.

The optimization of the BOM selection process requires the presence and processing of the components necessary for the construction of an optimal BOM so that a database can be created. The first element is an updated supplier information sheet, which should include the cost of a particular

(or minimum) quantity of an item, the lead time, and a company rating, or experience, factor for that specific supplier. The full product data are then extracted and stored in a variable in the same structure where the pre-arranged Excel sheet is located. The next step incorporates all generic BOM structures, which serve as a “skeleton” for constructing an optimized BOM. All BOM structures required for a particular project are extracted in a system-specified format from each construction work package.

For the ICMM system, every generic BOM is placed in its own unique Excel sheet. A generic BOM file contains the item name, item code, units, hierarchy, and quantity for all subassemblies and primary products. The “level” column indicates the placement of an item, with a value of 1 being the highest-placed subassembly for the particular product. The system filters all subassemblies and obtains the products and product quantities necessary for the completion of a requisition order for a particular BOM. This process is run for all BOMs imported into the system, and a database of product requisition order templates, complete with item quantities for each unit of that specific BOM, is generated and stored.

The last step involves the extraction of the user-specified Excel sheet containing the weighting factor for each criterion in the updated supplier information sheet. If all data are present, the user should open the GUI and start up the system. Once the processing algorithm is initialized, the BOM system loads the first GUI and then checks for an existing product as well as a materials list database. If none is detected, the user is prompted to load every generic BOM structure sequentially for every product, following which a product database is created. The user next selects the materials management spreadsheet, which the system reads and stores within a new materials list database. Finally, the user is prompted for the weighting factor spreadsheet, which is also then stored.

6.4 ICMM Validation

This research was sponsored by one of Canada’s largest construction and infrastructure development groups, who also provided the data used in this research to validate and optimize the proposed system. Over the years, this group has been involved in the building of some of Canada’s most important landmarks: the CN Tower, the 407 Express Toll Route, the St. Lawrence Seaway, the Vancouver Sky Train, and the Montreal-Trudeau International Airport. The group supports the research due to the fragmented nature of construction materials management and the immense costs involved in solving the associated problems. The ICMM system has therefore been developed as part

of a cost-effective solution to these challenges. The following case study provides an understanding of the way the system can be developed and implemented for specific construction projects. Because the names of suppliers and all details associated with the contracts must be kept confidential and may not be made public, capital letters are used as anonymous designations for suppliers.

In this case, the project included roughly 700 work packages, all of which had to be leased using a BOM. For the purposes of this study, only the building of a complex piping module was addressed; its construction is discussed with respect to the implementation of the BOM management and optimization system as a means of illustrating the production of an automated final draft order. Figure 6-8 illustrates the components of a typical piping module.



Figure 6-8: Components of a Typical Piping Module

For the module used in this validation, five different potential suppliers of the required materials were available. After the pre-evaluation process, three suppliers were refused by the project management team. However, the approach to selecting the best option was sophisticated nonetheless, and the project management team was faced with a constraint: awarding contractor A at least five items as this contractor is the trusted contractor and they wanted to maintain their relationship. Figure 6-9 depicts a portion of the BOM structure for this project, showing the item name, item code, units, hierarchy, and quantity for all subassemblies and primary products. The cost column in this figure represents only the best cost option after the optimization process was run.

Item	Code	Unit	Quantity	Cost
FT 12" XH 1333 GR6 SMLS DR	1154788	inch	170	21590
FT 12" XH 1333 GR6 SMLS SR	1154328	inch	270	36625.5
FT 12" XH 1333 GR6 SMLS SR – Hydro Testing	1154242	inch	20	2713
FT 8" XH A333 GR6 SMLS	1158486	inch	20	900
FT. 15" XH A106B SMLS DR	1166788	inch	80	392
FLANGE 12" PN100 RFWN XH A350LF2 CL1	1165879	inch	10	5650
FLANGE 8" PN100 RFWN STD A350LF2 CL1	1165910	inch	1	245
FLANGE 4" PN100 RFWN STD A350LF2 CL1	1165941	inch	3	195
FLANGE 2" PN100 RFWN XH A350LF2 CL1	1165972	inch	4	224
FLANGE 4" PN100 RF BLIND A350LF2 CL1	1166003	inch	1	72.25
FLANGE 2" PN100 RF BLIND A350LF2 CL1	1166034	inch	2	59.4
ELBOW 90 LR 12" XH A420WPL6	1768688	inch	13	9360
ELBOW 90 LR 8" STD A420WPL6	1768755	inch	2	790
ELBOW 90 LR 2" XH A420WPL6	1768822	inch	1	7.15
ELBOW 90 1.5" 3M THREADED A105	1768889	inch	11	135.85
CONIC REDUCER 12" X 8" XH x STD A420WPL6	1768956	inch	3	2250
NIPPLE PBE 1.5" XH 4" LONG A106B	1769023	inch	9	54
NIPPLE TBE 1.5" XH 4" LONG A106B	1769090	inch	24	103.2
SWAGE CONC THRD 1.5" x 0.5" XH A234WPB	1157777	inch	6	101.7
UNION THRD 1.5" 3M A105	1323255	inch	8	111.6
BULL PLUG HEX SOLID BODY 1.5" 6M A234WPB	1766978	inch	8	98.4
BULL PLUG HEX SOLID BODY 0.5" 6M A234WPB	1766646	inch	7	37.8
TEE STRAIGHT THRD	1687878	inch	10	158
SOCKOLET 30" x 1.5" 3M A105	1168688	inch	4	27.2
SOCKOLET 12" x 1.5" 3M A105	1165678	inch	4	27.2
SOCKOLET 8" x 1.5" 3M A105	1164564	inch	1	6.8
SOCKOLET 12"-8" x 1.5" 3M A105	1168877	inch	2	13.6
WELDOLET 36" x 2" XH A350LF2	1798998	inch	2	127.6
BUSHING THRD HEX BODY 1.5" x 0.5" 6M A105	1454555	inch	5	21.75

Figure 6-9: Sample Portion of the BOM Structure

As mentioned previously, when a request is issued by an authorized person (e.g., the project manager, superintendent, or project engineer), the required quantity of the product is multiplied by the appropriate amounts listed in the generic BOM, and the first draft is prepared. This draft order must then be compared with the warehouse inventory stock. The warehouse component of the ICMM system, which is specified to be integrated with the other elements of the system, is intended to record whether the item is a new or replacement material, a safety- or augmented-quality material, measuring and test equipment (M&TE), a rotatable spare, or a lead-time item and whether it is

covered by the maintenance rule. The basic question is whether there is enough inventory on hand to meet all demand requirements. If a sufficient quantity is available, the demand requirements are satisfied through the use of the inventory quantities, which are then delivered to the site according to the plan. Otherwise, a demand requirement is processed for the procurement of new inventory in sufficient amounts to meet the original demand requirement. This process requires a robust warehouse system for the control and management of all activities related to the receipt, inspection, storage, counting, distribution, issuance, and shipping of equipment and materials. Following this comparison, the draft of the purchase order is ready, and the system is run in order to obtain the optimal solution, which is the final purchase order. The running of the program and support for this part of the system requires accurate information about suppliers, which must then be entered into the proposed system. For the purposes of illustrating the developed process, one of the 700 critical construction value packages is presented in this section. It should be noted that this process is identical for all packages of this project. For this case, the information detailed in the following paragraphs was provided by the purchasing department team (Appendix J).

Suppliers A, B, and C have almost the same characteristics, and their location in the same locale as the project site would entail no delivery fees. These suppliers also have knowledge of the policies and delivery procedures used by the Canadian group of construction companies and are on the group's Approved Suppliers List (ASL) because of years of proven reliability in supplying several projects. Other characteristics that were considered with respect to each individual supplier included quick order turnaround time; consistently correct documentation accompanying shipments; immediate correction of order problems by the inside sales contact; immediate correction of invoicing issues and prompt issuing of credits; early payment discounts for payments made within the specified terms; and status as a preferred supplier of the construction group companies involved, which entails valuable year-end sales rebates.

The database information about suppliers D and F showed that neither of these suppliers is local, so additional delivery fees would be charged. Suppliers D and F are also not on the ASL for the group of companies, which means that both suppliers would be required to complete an evaluation form and submit it to quality control for review and possibly audit. The quality control department would also have to evaluate and then approve or deny all materials, a process that can be quick or lengthy, depending on the supplier's certifications, qualifications, and internal quality programs. The following factors were also applied and considered before the system was run: unknown order

turnaround time in spite of the requirement to submit documentation with orders, no guarantee that documentation will accompany the order and contain the correct heat/lot numbers, lack of assurance that problems with the order will be addressed as quickly as with suppliers A and B, lack of assurance that invoicing issues will be corrected as quickly as with supplier C, no advantage for early payment discounts, no status as a preferred supplier of this industrial group, with no ensuing year-end rebates.

After the system was run, using all of the processes explained previously, the score for supplier A was determined to be 13.8; for supplier B, 12.7; for supplier C, 12.9; for supplier D, 3.9; and for supplier E, 3.5. For the optimal scenario consideration a combination of selected suppliers, the score of 13.9 was achieved. The system therefore suggested the combination as the best option: the materials should be purchased from suppliers A and B. It should be noted that even after selecting best items and initiating the purchase order, the purchasing department would still need to negotiate and finalize the contract details with the successful supplier. The following table summarized our findings through implementing the ICMM for this project.

Table 2: ICMM Information for the Case Study

Project Info.	Number	Description
Construction Value Units	700	Number of CVP may change during a project execution but it must be less than 2%
Trusted Potential Suppliers	2350	EPC has a acceptable experience with these supplier
Investigated Potential Suppliers	600	Three potential supplier at least should be assigned for each item
Total Items (materials & equipment)	78400	Added up the items of all BOMs
Bulk Item	25000	Replicated items in different BOMs
Actual Item	45000	Items for proceeding
Awarded Suppliers	2850	These supplier may prepare materials/equipment for different CVPs

For this case study, partial sensitivity analysis has been performed for the weight-vector through changing a parameter and rerunning the optimization routine. In other words, managers change the weight of criteria and examine the impact that the change has on the system's results.

In practice, the factors affecting the purchasing decision process are changing from project to project. Thus, project managers can control the process through alterations in the weight of attributes. This approach could provide valuable insights into the robustness of purchase-decisions. Different

scenarios were considered for this study (Table 3). For example, Scenario 6 occurs when project managers figure out the project execution is far behind the project schedule so that they increase the weight of lead-time. Scenario 5 could be considered when project managers decide to purchase items at lower prices. Table 3 shows the different scenarios' results. Any changes in weight of criteria may change the results; however, the outcomes of some scenarios are identical for this specific study.

Table 3: The Consequence Table in Sensitivity Analysis

	Case	Senario 1	Senario 2	Senario 3	Senario 4	Senario 5	Senario 6
Price	0.2	0.25	0.3	0.4	0.3	0.5	0.2
Lead Time	0.3	0.25	0.2	0.4	0.3	0.2	0.5
Performance	0.4	0.4	0.4	0.1	0.3	0.2	0.2
Early Payment	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Awarded Supplier(s)	A & B	A & B	A & B & C	A & B	A & B & C	A & B & C & D & E	A & B & C & D & E

6.5 Conclusions

The ICMM system model presented in this chapter has the potential, if fully implemented, to significantly improve construction supply management processes and thereby lead to enhanced procurement performance. The developed system is based on consideration of most activities associated with the procurement of materials: the processing and administration related to purchase requisitions, purchase orders, internal supply requests, materials contracts, the expediting of materials, shipping, and costs. The design and implementation of an ICMM system for the efficient procurement of construction materials has been described. The implementation of the system and the associated case study results indicate that the system has the potential to be a valuable tool for project managers. Despite the successful research effort presented in this chapter, the system needs further development and enhancement. For example, one remaining challenge is determining how to connect the system to the materials management systems of the trusted suppliers (Appendix E), additional automation and integration that may significantly improve our system.

Chapter 7

System Integration through an ACSNM Database

With the use of electronic product and process management systems and associated solutions, such as the Advanced Construction Supply Nexus Model (ACSNM), islands of automation are becoming integrated via the internet at an accelerating rate. Enabling this integration are data standards and interoperability initiatives that have been underway in the construction industry for more than 30 years. Examples include the Industry Foundation Classes (IFC) models used in facility object-modeling environments, such as the various types of building information models (BIMs) and their industrial equivalent, ISO 15296. Managing the interrelationships or interactions among value units for complex projects can facilitate the implementation of related techniques in a dynamic construction environment. Lack of effective communication and poorly coordinated and controlled boundary conditions during a project cause a number of problems: mismatched parts, system performance failures, coordination difficulties, and site management conflicts.

Figure 7-1 shows how the ACSNM database can provide the integrating mechanism for overseeing the entire data and information environment of a mega construction project. It should be noted that what is presented in this chapter is a model for the ACSNM database, parts of which are implemented in a hosted EPPMS solution provided by Coreworx Inc, the research partner of this project.

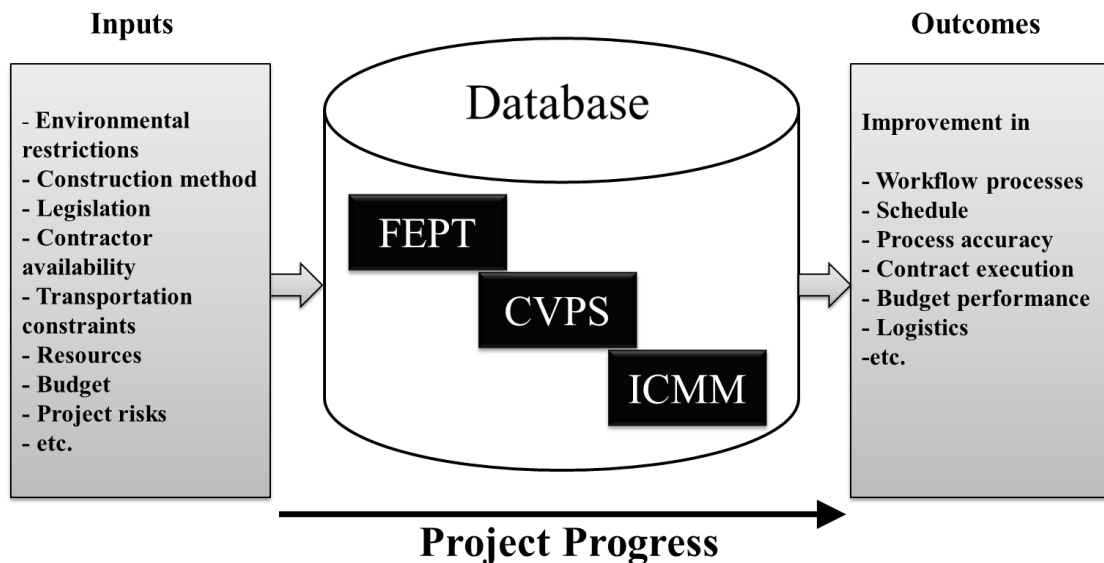


Figure 7-1: ACSNM Database and Other ACSNM Elements

From a construction supply nexus perspective, integration refers to collaborative practices that elevate the communication environment to permit the unrestricted exchange of information about the elements of a project between the stakeholders and other participants. As a platform that maximizes the interoperability of information between different elements of the model, the ACSNM database, once fully implemented as presented in this chapter, is a core ingredient in the enhancement of such integration for construction megaprojects. This chapter describes how data and information are managed through the database and explains the database requirements and functions. The integration of value packages with the use of the database and the associated advantages are also presented.

7.1 Data and Information Management in the ACSNM

The objective of the development of the Advanced Construction Supply Nexus Model (ACSNM) database model was to provide an integration platform for the developed supply nexus management system, as a means of supporting the activities associated with the Front End Planning Tool (FEPT), the Construction Value Packaging System (CVPS), and the Integrated Construction Materials Management (ICMM) system. Effectively addressing the activities within the developed supply nexus model required the following functionalities:

1. **Document Control:** Secure document control supports revisions, flexible metadata views, and document handling. The document management system meets the distinct and varied stakeholder needs with respect to accessing, reviewing, tracking, packaging, and handing over documents.
2. **Design Review and Approval:** Efficiency and consistency are improved through the leveraging of automated business processes for the selection of resources, the assignment of tasks, and the routing of documents for review and approval. Industry best practice are employed for the tracking and auditing of document activities conducted by internal and external review participants.
3. **Management Reporting and Dashboards:** Visibility and accountability are ensured across projects through real time data reporting with respect to document access, workflows, and user activity.
4. **Transmittals and Vendor Portal:** External participants, such as vendors, are provided with a secure portal for project collaboration that supports inbound and outbound transmittals as

well as associated document control processes. Tightly integrated, automated, and auditable processes drastically reduce time, effort, and risk.

5. Document Viewer and Markup Toolset: Project members can review and collaborate on all types of records, from MS Office documents to 2D and 3D CAD drawings, without the requirement for native applications.
6. Search functions: Users are empowered to find what they need, when they need it, using simple or attribute-based search functions across the entire project.

In addition to the above functionalities related to database management, a number of process-related functionalities that are critical to the successful implementation of the developed supply nexus management system are included: workflow management, document change management, and maintenance of an auditable historical archive. Details are presented in the following sections.

7.1.1 Process Management Using Workflows

Workflows play an important role in providing integration and automation of supply nexus management processes so that information can be communicated in a manageable way based on procedures. The ACSNM developed through this research is a web-based model that utilizes workflows for automating and integrating the supply chain processes. The developed model provides superior integration of document control, enhanced consistency, fewer errors, improved communications, and automated supply nexus processes for construction megaprojects. The electronic product and process management systems help control the delivery of tasks to the correct people, provide a thorough audit trail, and send notifications if required.

Once the value packages (VPs) are developed during the construction and subsequent phases, all information and data must be entered on the forms that have been created for facilitating data entry. In this phase, the operators enter the data into the system, and the supervisors or other assigned employees then check all the approved changes and rejected entries, as well as the entry status report, which shows the number of entries and dates. Based on all of this input, the system provides monitoring reports for a variety of management levels. Data entry requirements appear as subtasks that must be assigned to the appropriate people by the top management level for the project. To facilitate this process, several reports must be developed, based on the project requirements, and the separate steps for approving all the data entered must also be considered (Figure 7-2). For example, when operator A enters specific data, operator B must check and control these data, and supervisor C

must check the data for approval. Of course, the exact sequence is entirely dependent on the specific characteristics and levels of the data.

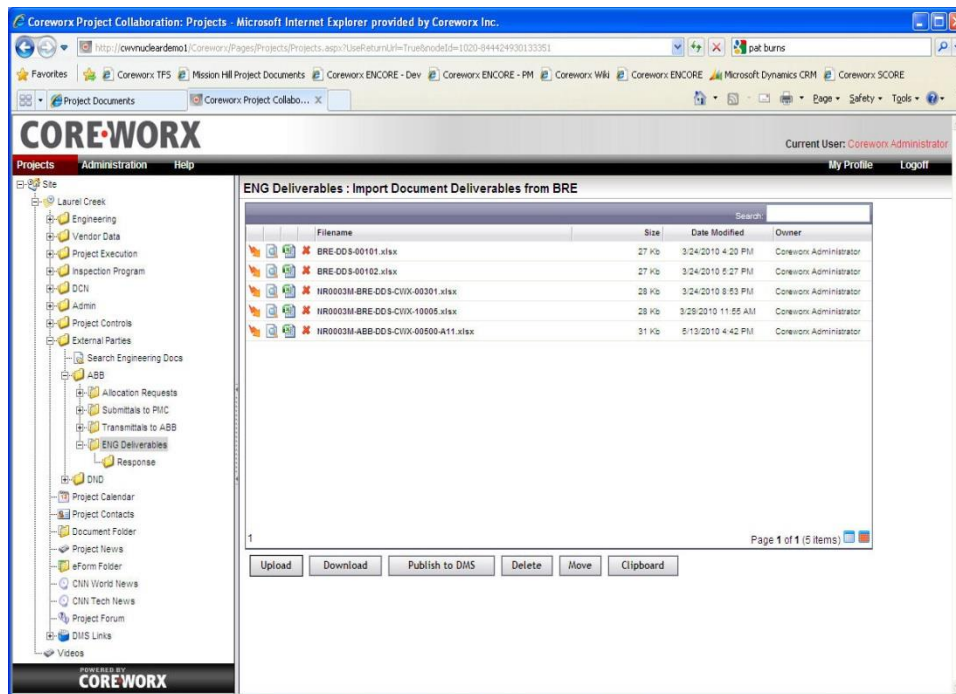


Figure 7-2: Import Work Process Deliverables – Process (Actor: Project Team Member)

The design review and approval work process represents the automation of the standard design review procedures that the owner has used when working with the Front End Planning Tool (FEPT). All documents that are exchanged between the owner and the contractor and that are identified in a controlled scope of work are automatically sent on to the design review and approval process. It is critical that this workflow be designed to coordinate with the FEPT because during the front-end planning (FEP) phase, poor communication among and ineffective management by top managers and experts (engineers) can result in substantial losses with respect to time and other resources.

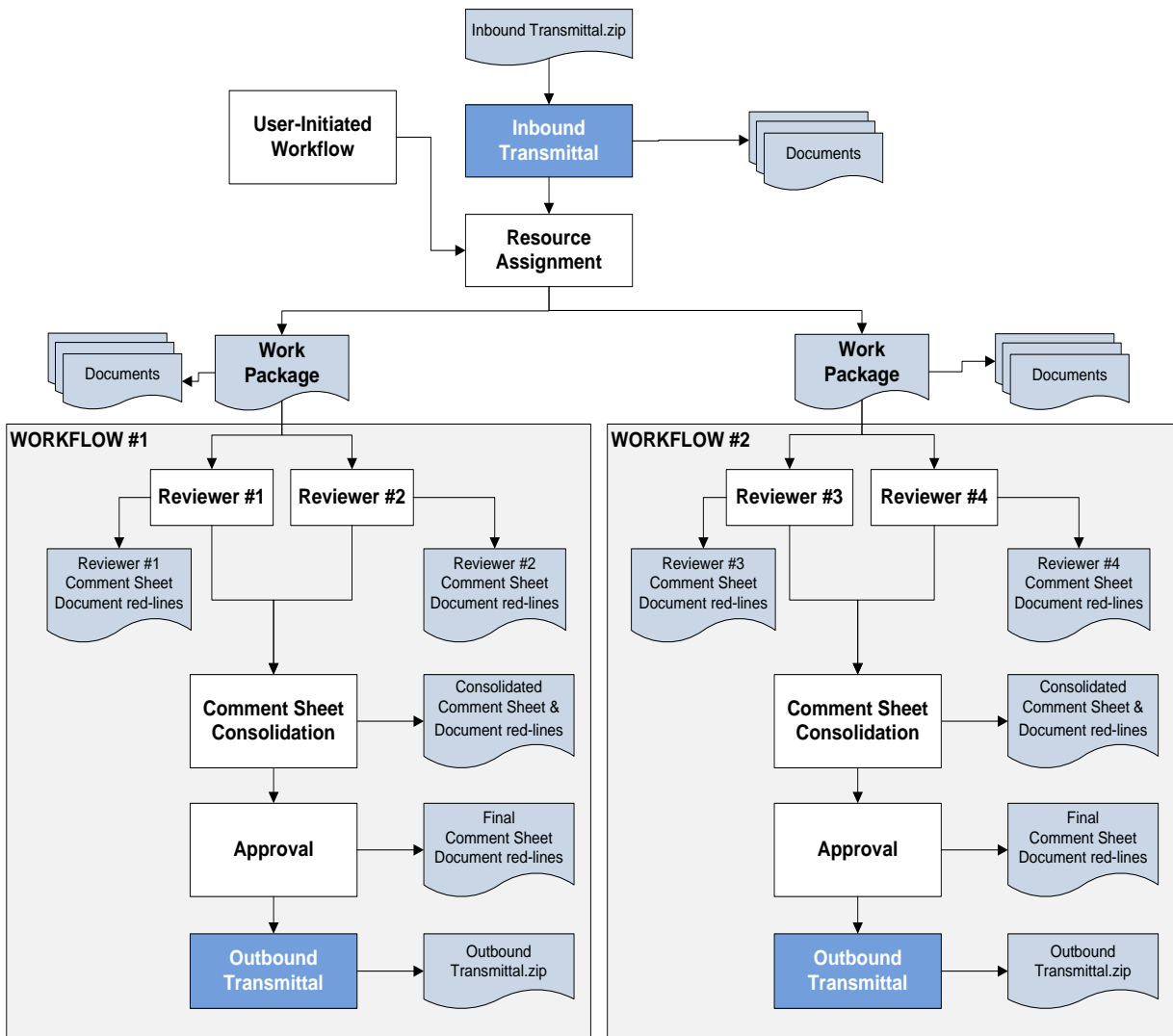


Figure 7-3: Flow Diagram of the Design Review and Approval Process

The primary activities in this workflow are inbound transmittal, approval, consolidation, and review:

1. Inbound transmittal initiates the workflow when documents are received from an external party (or an internal team) via an inbound transmittal. All validated documents are loaded into the appropriate document archive, along with the metadata.
2. The approval process occurs when the approver makes a final determination with respect to whether the value package is marked approved, in which case, all documents are accepted as approved and requiring a response. The external party (or internal team) must then provide disposition comments that satisfy the approver before the value package receives final approval.

3. Consolidation ensues when a VP is complete and the approver is immediately sent an approval assignment.
4. During the review stage, each reviewer is responsible for evaluating the entire work.

A good example of a workflow process in the developed model is the change request workflow, which might be employed in the construction supply nexus model. For instance, any changes in the design or schedule of the value packages may affect the design and BOM, interface agreement, or other characteristics of other packages. The change request workflow should therefore be effectively designed to perform based on the project's description and features. In the change request workflow process, information about modifications is captured and then sent through a review cycle so that the the impact on both finances and the schedule can be assessed, following which the request is then sent for either approval or rejection. A project team member, the customer, a contractor, or a subcontractor can (with proper permissions) initiate a change request (Figure 7-4).

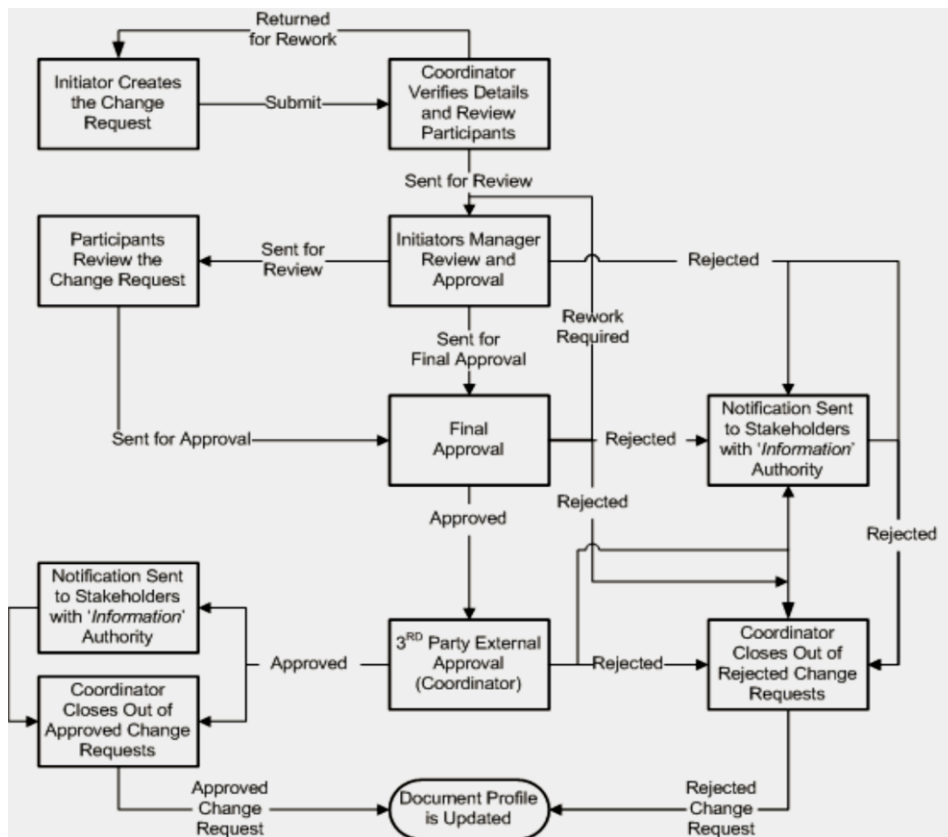


Figure 7-4: Change Request Workflow

Using the change request form, the initiator identifies the reason for the change and establishes the importance of that change. After the change request has been submitted, all those responsible for assessing, reviewing, and approving the change request receive it for their attention, according to the RACI matrix explained in Chapter 4. For example, a manager approves the change request before the review participants have the opportunity to examine it.

7.1.2 Document Version Control

The ACSNM uses a document structure that adheres to industry best practices with respect to version control. The document model is a hierarchy in which each level is governed by version control and is based on independent metadata. The base document, which is referred to in the ACSNM as the “document profile,” is the lowest level, where document revisions and files are grouped together. For each level of the hierarchy, the ACSNM manages distinct metadata, including attributes, relations, history, milestones, markup, and other information, for multiple versions of the same document file as well as for multiple files in a document or a document revision. These versions can include an original PDF file, one or more marked-up PDF files, original native format files, and any other combination of files and file types, as shown in Figure 7-5.

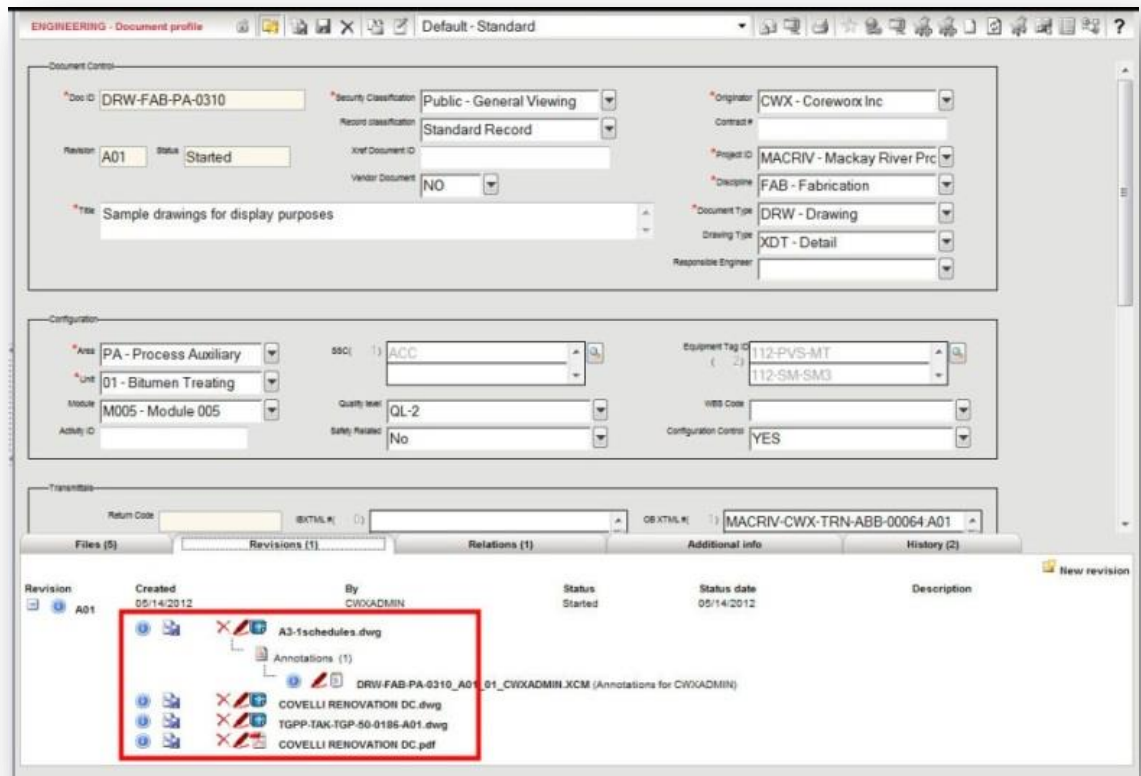


Figure 7-5: Document Revision with Multiple Files

When multiple engineers, often from different companies, are accessing the same document profile, security and an audit trail become crucial. The ACSNM provides authorized users with access to audit trail data for documents, document revisions, and files. The audit trail data for the document profile provide a complete list of events associated with the document, including performer, date, and a description of the event (including any changed data). The document issuance history is also accessible from the document profile.

7.1.3 Historical Database

Finally, once critical documents have been issued and approved, some of them must be protected from modifications or tampering. The ACSNM provides a lock function so that authorized users can prevent changes to historical documents and data. The lock function is commonly used when documents are subject to records management disposition and retention rules.

Project data is stored in the project database along with a variety of cross-project data, such as users, categories, and audit and report types. The data could reside either in an individual project database or in a project database shared with other projects. The project database offers the ability to archive all data associated with a project with enhanced simplicity and efficiency.

When the construction phase has ended and the start-up is complete, the documentation for the project in the form of tens of thousands of documents, electronic files, as-built models, and specifications must be transferred smoothly to the historical database. So that it can be used in the future, the information is stored in the database, including lists of successful value unit providers (VUPs), rework activities, human resource issues, model problems, unpredicted challenges, procurement information, and other results and outcomes of the project. The historical database is thus a source of guidance for producing efficient and effective future decisions because it enables easy access to previously successful well-structured approaches and well-focused processes that can be reused for any upcoming projects.

7.2 Value Package Integration within the ACSNM

The interface management integration component of the ACSNM supports a structured approach to handling and managing interfaces for large capital projects, starting with the FEP stage and progressing through other stages (Appendix K). In other words, interfaces are normally identified very early in the life cycle of a mega capital project, when the opportunity to impact project risk is highest. The ACSNM interface management integration processes maximize the ability of the project team to capture such opportunities and to minimize the risk during the concept phase, before costs are incurred.

Chapter 5 explains how the supply nexus management process starts with the identification of the value units and then progresses to the identification and creation of value packages. Based on interface agreements, contractors who are awarded a contract are then responsible for managing the interfaces (between value packages) in order to document deliverables and provide any information required by other VUPs (Appendix K). Mutual agreement and acceptance are required from both parties before the interface agreement can be finalized (Appendix F). This step cannot be accomplished unless all contractors collaborate effectively with the project management team. Once the appropriate VUPs are determined, all relevant VUPs must be notified so that the optimization process can be coordinated. Both the owner and the VUP benefit from this collaboration. To clarify

any VP overlaps or new detailed planning (amendments), VUPs must enter their information into the system, including their own logistics plan (shipping and receiving schedule); the inventory space required for materials, equipment, and predicted surplus materials at the site; and a human resources schedule. The overlap between VPs with respect to materials; equipment; and in some cases, workforce can be managed and optimized by the project team through the system developed in this research, as shown in Figure 7-6. It should be noted that a comprehensive reporting system is necessary for the management of this phase.

Based on the VUPs' input, the system can coordinate the logistics for the equipment in order to determine the dates when the equipment is required at the site. VUPs can then share and coordinate the rental of equipment. For example, if several VUPs require a specific crane for different VUs, by changing the VU schedules (optimization) and by taking the critical path into account, they can share one crane. Several resource requirements can thus be combined into a single order for a single vendor or supplier.

The model facilitates the complete procurement cycle process through an effective materials management . If no specific constraint exists, the material plans for an item required for several VPs can be optimized as a unique plan. In the absence of the VUPs' information about materials procurement, the project team predicts the initial information as part of the VP. Materials estimation with respect to transportation to the site should include the type of materials, the site storage and warehouse capacity, and site gates and security. The number of containers to be filled and hauled should then be estimated for each type of material, and the volume of each type of material should also be estimated so that it corresponds to site capacity. Each item received can be assigned to a storage location and can later be relocated if necessary.

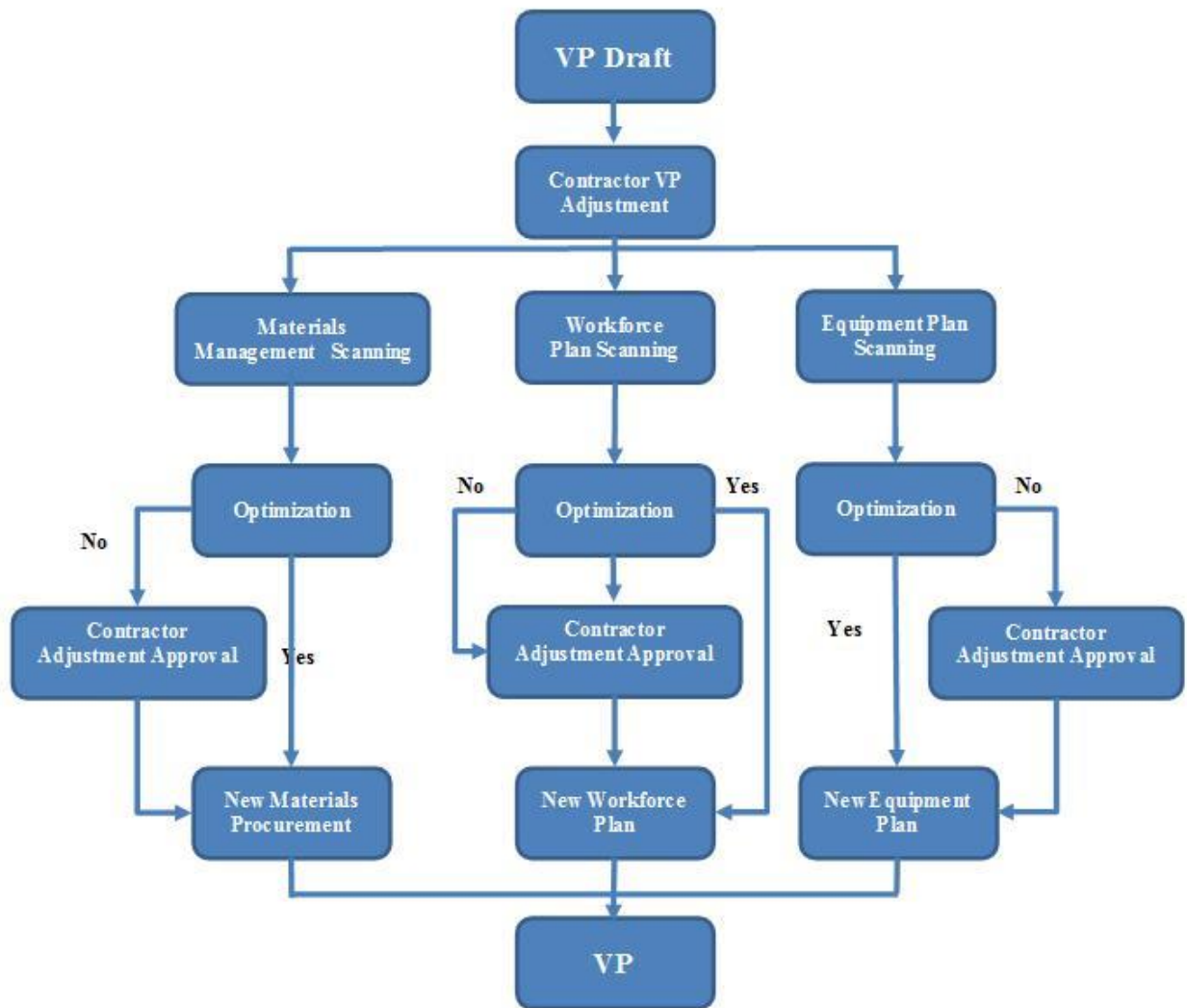


Figure 7-6: Value Package Optimization

North American construction projects have been affected by a number of challenges associated with human resources, including workforce training, allocation of workers on construction projects, and a shortage of skilled workers. However, a construction project based on a VP approach is characterized by multiple tiers of VPs and is always associated with a group of skilled or semiskilled craftsmen who belong to a specific VP. This method helps the adoption of labour-sharing and multitasking strategies less difficult because alternative skilled labour can work in different VPs and at different tasks. This strategy may enhance project performance and reduce shortages and wastage through better use of the existing workforce. In this phase, the cost impact of time, duration, and quality

tradeoffs is considered. The objective of this phase of the model is also to minimize labour costs while satisfying project labour demands, which provide an incentive that, will encourage contractors to adopt the VP labour policy (optimization). However, various factors, such as contracts' scope, suppliers, financial issues, and site supervisors' preferences influence the VP labour policy (Alvanchi, 2012).

The contractors provide the following input into the proposed model: a specific available labour pool, estimates of the number of personnel required, the necessary affinities between the different skills considered, the worker hiring schedule, and the requisite hourly labour rate. The model provides all information for an optimization-based framework that enables skilled construction labourers to be matched most efficiently through effective allocation based on the VP approach. For example, if contractor A needs an electrician for two days for VP1, and contractor B hires an electrician during the performance of VP2, it might be possible, within given constraints, for contractor B's electrician to assist with the work in VP1. In the opinions of Coreworx clients and experts, this part of the model, in particular, represents a significant advancement.

Taking into account the above process, the project team can systematically identify, analyze, and develop responses to interface risks and to barriers to communication and coordination that may arise with respect to two VUPs, VUs, or VPs. Project managers and decision makers are also equipped with powerful reports that enable them to easily monitor and control the progress of the interface points throughout the life cycle of the project.

7.3 Summary

The ACSNM also requires some services such as: database management, web-based delivery, interoperability, workflow engine, document management, automating and integrating mechanism, and historical database and knowledge management. One of the important required services is a historical database. The historical database is a basis of guidance for providing effective future decisions, because it enables easy access to previously successful well-structured approaches and best practices information that can be re-used for any upcoming projects. Several construction software companies provide such a product with these capabilities. An Electronic Product and Process Management System (EPPMS) is a good example which is introduced by Coreworx.

Chapter 8

Conclusions and Recommendations

8.1 Conclusions

This thesis has presented a comprehensive Advanced Construction Supply Nexus Model (ACSNM) for managerial applications in the industrial sector of the construction industry. The objective of this research was to develop and validate the mechanisms for a model that provides guidance with respect to improving construction supply nexus decision-making and managerial processes. The basic elements and concepts underlying the ACSNM functions have been discussed. This research indicates that managing the construction supply chain involves five closely interrelated elements: a front-end planning tool (FEPT), a construction value packaging system (CVPS), an integrated construction materials management (ICMM) system, an ACSNM database, and an underlying system of software services such as a workflow engine. The successful development of the model therefore also required cross-functional integration. Hence, this work included effectively addressing process management, process integration, and document management for construction supply nexus processes, areas that have not been developed in previous implementations of similar models in construction-related applications.

The development of all elements of the ACSNM entailed close collaboration with experienced experts from leading Canadian Engineering Procurement and Construction (EPC) companies. One of the important elements of the developed model is the FEPT. As demonstrated in this research, its use increases the efficiency and control of the front-end planning (FEP) process and allows the rapid implementation of a solution that can accommodate a compressed schedule while supporting an enhanced level of control and quality with respect to FEP deliverables. Some of these FEPT deliverables then become the input to the next step: the CVPS.

The CVPS has been developed based on a set of value packages that is an optimized aggregation of value units. The creation of the value packages requires the early collaboration of the architect, the contractors, and the other stakeholders in the project; the information stored in the historical database and the knowledge provided by specialists and experts are therefore extremely valuable during this process. These are also valuable in the case of litigation or post-construction claims. The CVPS is thus considered a creativity tool that functions as a guide for improving the efficiency of the bidding decision process because of the decreased time required for a decision and the generation of options

that may not otherwise be identified. The results of the case studies and the feedback from industry partners indicate that the model is a valuable tool for construction project management.

Construction materials management accounts for a large portion of construction supply nexus management and has a significant impact on productivity. An Integrated Construction Materials Management (ICMM) system model has been presented as part of the ACSNM. Overlapping and supporting the CVPS, the ICMM system has the potential to improve construction supply nexus management processes and thereby enhance project performance. The developed model is based on consideration of the majority of activities associated with the procurement of materials: the processing and administration related to purchase requisitions, purchase orders, internal supply requests, materials contracts, the expediting of materials, shipping, and costs. The incorporation of these features into the design and implementation of the ICMM system has the potential to result in the efficient procurement of construction materials and makes this system an important component of the ACSNM.

A genuinely integrated construction supply nexus management model requires a robust structure and massive commitment from all members of the project value chain. This research has shown that the designed database model hosted by a full-scale EPPMS framework, within the model requirements and the workflow concepts, can successfully and efficiently regulate this integration. Case studies conducted at several construction megaprojects and involving multiple members of the supply nexus were used as a means of illustrating and validating the concepts described.

8.2 Contributions

The main contribution of this research is the development of a comprehensive supply nexus model (ACSNM) for the integration of the critical elements of the construction supply chain. The literature review, discussions with scholars, attendance at a number of construction management conferences, and consultation with experts in this field have all revealed a compelling need for comprehensive and integrated supply nexus management for the construction industry. The work conducted has provided specific significant contributions to five major areas of study: (1) the development of a comprehensive supply nexus model, (2) the provision of Front End Planning Tool (FEPT) for the strategic management phase of projects, (3) the development and demonstrated use of a state-of-the-art construction packaging system for contract management, (4) improvements in current construction

materials management systems, and (5) advances in document management. This section provides a brief discussion of the specific details of these contributions.

- 1) Construction supply nexus functions must operate in a coordinated manner in order to optimize performance at the tactical and operational levels and so enable access to timely information that enables the accurate coordination of decisions and processes. The key contribution of this study is the development of a comprehensive Automated Construction Supply Nexus Management (ACSNM) system model, with clear integration of its five components: the FEPT, the Construction Value Packaging System (CVPS), the construction materials management system, the data management system, and an underlying system of software services such as a workflow engine.
- 2) Based on a review of some of the significant work and published papers that have contributed to providing the methods and tools for the strategic management of construction megaprojects, it was apparent that an abundance of tools exist for use during the FEP phase of construction projects. The FEPT developed in this research, which provides support for owners and major contractors who are engaged in FEP, is based on a series of workflows that adhere to industry-accepted best practices and that are delivered through an electronic product and process management system. The implementation of the developed FEPT in three construction projects generally demonstrates its potential for producing higher levels of overall project performance.
- 3) Construction packaging constitutes a new modeling paradigm especially suited to the complex and dynamic processes inherent in a mega construction project. The larger the construction project, the more challenging the task of optimally dividing and then packaging the work for the multiple contractors and suppliers involved. In this research, a CVPS was developed with the facilitation of construction contract management at its core. The system serves as a computational and process environment that is intended to assist with project leaders in their efforts to increase the efficiency, auditability, and effectiveness of the procurement process. The results of the case studies and the opinions of experts indicate that the model is a valuable tool for construction project management.
- 4) This research has contributed to the body of knowledge related to construction materials management through the development of a framework that permits the interfacing and automation of the construction materials procurement process. As part of the ACSNM, an ICMM system

model was developed and core algorithms implemented that have the potential to improve construction supply management processes and thereby lead to enhanced project performance. The ICM system ensures that selected materials are delivered quickly and directly to construction sites, in a manner that conforms to project requirements and constraints, such as price, lead-time, cash rebates, supplier performance, and preferred suppliers.

- 5) The ACSNM is a web-based system that utilizes workflows for automating the construction supply nexus management system. The process-based model is built on a workflow-driven structure, whose use for improving supply nexus processes constitutes an additional contribution of this research. With further enhancements to the developed supply nexus management model, these workflow-driven processes can evolve into industry foundation standards.

8.3 Limitations

The ACSNM and its elements that were developed through the research presented in this thesis were designed and validated in several case studies involving construction megaprojects. Because of the constraints associated with a Ph.D. research program, the following limitations were taken into account during the creation, validation, and implementation of the ACSNM:

- 1) Relative to the broad scope of construction megaprojects, the implementation and validation of the developed ACSNM system were limited. The time frame of a Ph.D. research program precludes the validation of the overall ACSNM system throughout the life cycle of a construction megaproject, which may have a duration of up to 20 years. While the information that could be derived from this study, given the limitations, is considered valuable for the industry, the model should be fully implemented for a complete megaproject in order to properly validate all aspects of the supply nexus management system.
- 2) To protect the investments of EPC (Engineering, Procurement, and Construction) companies in their enterprise and in their homegrown control systems, the developed model must provide an effective and reliable platform that can interface with these systems. The existing information technology infrastructure of these companies may range from multi-million dollar investments in enterprise resource planning (ERP) systems, such as SAP and Oracle E-business Suite, to homegrown or Microsoft Excel-based project or portfolio management tools. Given the inherent resistance of the construction industry to the adoption of new systems and technologies, the successful implementation of the developed model is highly

dependent on the success of such an integration platform, such as that provided by the research partner of this project, Coreworx Inc.

8.4 Recommended Future Research

The review of the published literature revealed very little empirical evidence that the construction industry is making a successful strategic transition toward an integrated or systematic framework for a comprehensive supply nexus management system. This research highlights the need for such a transition and suggests that further development and improvement of the ACSNM could integrate key elements of the construction supply nexus. For the future investigation of the FEPT, the CVPS, and the ICMM system, which constitute three main components of the research presented in this thesis, the following work is recommended:

- 1) This research represents one of the first attempts to provide a value packaging system (VPS) for the enhancement of the contract management process in mega construction projects. To provide a strong VPS, interface management should be applied for initiating and defining value packages as a means of both reducing the number of interfaces and establishing a higher level of control. The interfaces may be implemented between divisions of a single company or between companies that have no connection other than the work coordinated by such a system. This process should also be extended to the FEP phase of the project life cycle.
- 2) With respect to the further development of the ICMM system presented in this research, the application of the model for an entire construction project is recommended. The implementation of the model and the associated case study results presented in this thesis indicate that the model has significant potential as a valuable tool for project managers. The challenge for the future is to provide efficient and reliable interfaces so that the system can connect to the materials management systems of trusted suppliers. This automation and integration would significantly improve the developed model and would offer a more comprehensive and cohesive supply nexus management system for the construction industry.
- 3) One of the important elements of a truly integrated ACSNM system is construction quality assurance, which was beyond the scope of this research, but would need to be investigated for further improvements of the presented ACSNM framework. With the technological advances in the fields of 3D Laser Scanning and Photogrammetry in the recent years, an integrated and automated quality assurance system can be a natural continuation of this research.

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Appendix A
Supplier Pre-Qualification Profile Form Sample

NAME: [company name]
ADDRESS: [company address1]
[company address2]
[city],[state] [zipcode]

TELEPHONE: [telephone] FAX: [facsimile] Email [Email]
INITIAL COMPANY CONTACT - POSITION TITLE: [contact name],[contact title]

COMPANY REPRESENTATIVE COMPLETING THIS FORM:
NAME: [name] POSITION: [position] DATE: [mm/dd/yy]

OFFICIALS:

ORGANIZATION CHART ATTACHED YES NO; IF NO, IDENTIFY KEY REPRESENTATIVES:

PRESIDENT: [contact name]

VICE PRESIDENT: [contact name]

FINANCIAL MANAGER: [contact name]

SALES MANAGER:

PROJECT MANAGER

ENGINEERING MANAGER: [contact name]

PURCHASING MANAGER: [contact name]

PRODUCTION MANAGER: [contact name]

QUALITY MANAGER: [contact name]

NUMBER OF EMPLOYEES (FOR THIS FACILITY)

TOTAL [number] ENGINEERING [number] R&D [number] QA/QC
[number]
PURCHASING [number] PRODUCTION [number] PROJECT MANAGEMENT
[number]
OTHER [number]

UNION:

IF UNIONIZED, LIST THE UNION NAME: [union name]
CONTRACT EXPIRATION: [expiration date]

COMMERCIAL ASPECTS

NAME AND ADDRESS OF PARENT COMPANY, IF DIFFERENT FROM ABOVE

NAME: [parent company]
ADDRESS: [company address1]
[company address2]
[city],[state] [zipcode]

RATED BY DUNN & BRADSTREET: YES NO
D&B NUMBER: [D&B number]
OWNERSHIP: PUBLIC PRIVATE
FINANCIAL STATEMENTS AVAILABLE: YES NO
BUSINESS RESUME (Annual Report) ATTACHED: YES NO
GROSS ANNUAL SALES (of the last three years) in TUSD: [year 1], [year 2], [year 3]

PRODUCTION FACILITIES AND CAPABILITIES

SIZE OF FACILITIES (INDICATE UNIT OF MEASURE IN SQUARE FEET OR SQUARE METER)

TOTAL AREA: _____ OFFICE AREA: _____ WAREHOUSE: _____
WORK AREA: COVERED: _____ OPEN: _____

CRANE DATA

TYPE	NO.	CAPACITY	HEIGHT UNDER HOOK
_____	_____	_____	_____
_____	_____	_____	_____

WHAT IS YOUR FACILITIES PRODUCTION CAPACITY?
WHAT IS THE CURRENT CAPACITY UTILIZATION?
PRODUCTION (COMPLETE FOR EACH PRODUCT LISTED)

[project name]

[product supplied]

[p.o. number]

[project name]

[product supplied]

[p.o. number]

QUALITY MANAGEMENT SYSTEMS

Instructions:

1. Please send copies of your Quality Manual, ISO Registration Certificate if applicable.
2. Place a check mark in the appropriate box. Complete the "Comments" box as needed.

Is your company currently registered to a recognized QMS?						Year Registered:
If yes, what QMS? (ISO 9001:2000, QS9001, TL9001...)						
If yes, who is your registrar?						
IF YOUR COMPANY IS REGISTERED TO A RECOGNIZED QMS YOU DO NOT NEED TO COMPLETE THE REST OF SECTION 8 BUT YOU MUST SEND A COPY OF THE QMS CERTIFICATE OF REGISTRATION						
	Yes	No	N/A	Hours	Comments	
Do you have a documented Quality Manual?						
Do you have a documented Quality Policy Statement?						
Do you have documented Quality Objectives?						
Is responsibility and authority for the release of product defined?						
How much overtime occurs for hourly employees on average per week in the following departments?						
Manufacturing						
Quality						
Administration						
Purchasing						
Do you perform analysis of data relating to the following?						
Customer Satisfaction						
Conformity of Product						
Suppliers						

On the portion below, place a check mark in the designated box if the following applies:

Documented – there is a documented procedure or work instruction maintained that pertains to the issue.

Process Only – there is no documented procedure but there is a process in place that pertains to the issue.

Records Maintained – records are maintained to verify process has been performed

N/A – no process in place pertaining to issue.

Comments – you may write any additional information you deem important to the issue.

Does the company have a process:	Documented	Process Only	Records Maintained	N/A	Comments
to control documents?					
to control quality records?					
to determine necessary competence for personnel performing work affecting product quality? (I.e. job descriptions)					
to provide training for employees?					
to assess job performance for employees affecting product quality?					
to define and review customer requirements and verifying you can supply the order prior to commitment?					
to handle customer complaints?					
to verify the product conforms to the design?					
to validate the product is capable of meeting requirements?					
to ensure that purchased product conforms to specified requirements?					
to control the manufacture of the product? (I.e. shop traveler, M.O.)					
to validate any processes for production or service where resulting output cannot be verified by subsequent monitoring or measuring?					
for identification and traceability of product when required?					
to maintain and protect customer supplied product?					
for preservation of product?					
for calibration of monitoring and measuring equipment?					
to monitor customer satisfaction?					
to demonstrate conformity of product?					
to perform preventive action on potential nonconformities of products or processes?					
to qualify and monitor sub-contractors?					

Appendix B

Bid Analysis Form Sample

Project
 Specification Name
 Specification Number
 Date
 Revision No.
 Budget =

Bid Analysis

Prepared By _____

Planned Award Date _____

Note: Items in Blue will be Updated Automatically from Other Tables

TABLE 1: BID ANALYSIS SUMMARY							
	Sigma Thermal	Newpoint Thermal	Heatec				Comments
INTRODUCTION/SCOPE OF WORK							
a. BASE BID PRICE (From Table 2)							
COST ADJUSTMENTS							
b. Technical Cost Adjustment (From Table 3)							
c. Commercial Cost Adjustment (From Table 4)							
EXPECTED/FINAL CONTRACT PRICE (a+b+c)							
Expected/Final Contract Price vs. Budget (Positive Number Indicates Over Budget)							
Percentage Expected/Final Contract Price vs. Budget							
Expected/Final Contract Price Cost Difference (Expected/Final Price/Low Expected/Final Price)							
Percentage Difference vs. Expected/Final Contract Base (Expected/Final Price/Low Expected/Final Price)							
EVALUATING FACTORS							
d. Technical Evaluation (From Table 3)							
e. Construction Evaluation (From Table 3)							
f. Quality Assurance Evaluation (From Table 3)							
g. Commercial Evaluation (From Table 4)							
EVALUATED FACTORS SUBTOTAL (d+e+f+g)							
TOTAL EVALUATED COST (a+b+c+d+e+f+g)							
Evaluated Cost Difference (Evaluated Cost - Low Evaluated Cost)							
Percentage Difference vs. Evaluated Base (Evaluated Cost/Low Evaluated Cost)							
Conclusions/Recommendation: Budget: Awarded Cost: Forecast Adjustments: Final Cost at Completion: Over(Under) Budget: Recommendation: Tax note: Budget Note: Bidder note:				Schedule: Shipment: _____		Final Bid Analysis Approvals: Procurement _____ Engineering _____ Project Mgmt. _____	

Appendix C

Sample of Quotation

Date of Issue:

Proposal #:

Prepared by:

RFQ #:

To:

Black and Veatch Corp.

Phone:

Fax:

Attention:

E-mail:

Scope of Supply (Optional equipment listed on page 6):

Model	Description	Investment (U.S. \$)
HCI-10010-40		
Pump Assembly		
Start-Up		
Front Enclosure		
Total for 28 MM BTU		

Validity is 30 days. The proposed company retains the right during this period to change prices.

Delivery Period:

Weeks

Equipment Manufacturing

Drawings

*Based upon current engineering and manufacturing loads, which are subject to change. Long lead items will need to be ordered without approvals. However, we have checked with Engineering and for a new customer on a project like this, we can generate preliminary drawings showing outline and connection points in 3 weeks.

OPTIONAL ITEMS:

Model	Description	Investment
Emissions Testing		
Fuel Trainer		
Relief Valves		
Shell Construction		

Electrical Enclosure
Exhaust Stack
Air Separator

Hydrocarbon Detector

Insulation
Cable and cable tray
Oxygen Trim System
Spare Parts

Spare Parts List

SCANNER
MODULE PROGRAMMER EP170
MODULE DISPLAY ED510
MODULE AMPLIFIER EUVS4
CABLE RIBBON E350-3 {EXPANSION}
MODULE EXPANSION E320
RELAY RH4B-UL AC240V
SILICONE TUBE RED HIGH TEMP RTV
IGNITION TRANSFORMER
CONTROL TEMP LIMIT UT350L-00
CONTROL TEMP MOD UT450-04
SPARK IGNITER ECLIPSE VORTO
ELECTRICAL DAMPER ACTUATOR

NOTE:

This is a partial preliminary spare parts list. The complete parts list will be sent after the P.O. is received, and once we have the final scope defined.

SYSTEM PARAMETERS:

% Output	Duty (Btu/Hr)	% Eff (LHV)	Stack Temp (F)	% Output

Equipment	Length (Ft)	Width (Ft)	Height (Ft)	Weight (Lbs)	Mounting
Horizontal Heater					
Simplex Pump Skid					
Simplex Pump (HP)					
Panel					
Gas Train					
Exhaust Stack					
Blower (HP)					

Heater Capacity (Btu/hr) (MW)		
Heater Circulation Rate (Lb/hr) (kg/hr)		
Heater Circulation Rate (Gal/min) (m³/hr)		
Heater Inlet Temperature (°F) (°C)		
Heater Outlet Temperature (°F) (°C)		
Minimum Allowable Circulation Rate (Gal/min) (m ³ /hr) 80 %		
Input (HHV) (Btu/hr) (MW)		
Stack Temperature (°F) (°C)		

Calculated Heater Efficiency % LHV		
User / Valve / Pipe ΔP (psid) (kPa)		
Heater Calculated ΔP (psid) (kPa) (Clean)		
Pump Head Design (psid) (kPa)		
Heater Volume (Gallons) (m ³)		
User Volume (Gallons) (m ³)		
Total Volume (Gallons) (m ³)		
Total Surface Area (ft ²) (m ²)		
Overall Flux Rate (Btu/hr-ft ²) (kW/m ²)		
Radiant Surface Area (ft ²) (m ²)		
Average Radiant Flux Rate (Btu/hr-ft ²) (kW/m ²) AICHE		
Maximum Radiant Flux Rate (Btu/hr-ft ²) (kW/m ²) AICHE		
Maximum Metal Temperature (°F) (°C) AICHE		
Maximum Film Temperature (°F) (°C) AICHE		
Combustion Loading (Btu/hr-ft ³) (kW/m ³)		
Average Film Coefficient (Btu/hr-ft ² -F) (W/m ² -K)		
Average Reynolds Number		
Average Flue Gas Velocity Across Insulation (ft/s) (m/s)		
Average Oil Velocity (ft/s) (m/s)		
Average Prandtl Number		

Paint Schedule:

Equipment	Surface Preparation	Primer	Top Coat
Heater			
Stack			
Fuel Train			
Piping			

All purchased items will remain as painted from respective vendor. Thickness is 2-3 mils DFT.

Heater coil temperature design:

Heater coil pressure design:

Heater coil corrosion allowance design:

Heater coil code design:

Heater coil metal temperature calculation procedure:

DESIGN THEORY:

The proposed company manufactures both two and three pass heaters. We recommend the two pass heater for the following reasons:

- The average radiant heat flux for three pass heaters typically is much higher (Can be 60% higher). High average radiant heat flux causes high metal wall temperatures, leading to premature coil failure and premature degradation of the thermal fluid. It is not surprising that the average coil life of two pass heaters is 20 years, while the coil life of three pass heaters is usually half that.
- Since different methods are used to calculate the heat flux the only way to examine the heat flux uniformly is to compare the radiant area and the combustion chamber diameter (Radiant coil inside diameter). The coil with the greatest amount of radiant surface area and / or the greatest combustion chamber diameter will have the lowest radiant flux rate.
- The bolted cover(s) of the two pass design allow for easy coil replacement without replacing the entire heater or requiring shipment back to the factory for costly repair. There is more internal “room” in the less crowded two pass heater that allows for greater space between the flame and the coil, improving ease of inspection, lessening the chances for flame impingement and thus lengthening coil and thermal fluid life.

DESIGN THEORY CONTINUED (Lowest Radiant Flux Rate Heater on the Market):

- The velocity in coil is in the range of 6-13 fps as recommended by most thermal fluid manufacturers (quoted velocity is 7 fps). Due to the low average radiant heat flux of two pass designs, they do not have to rely on excessive coil velocity (which can lead to erosion) to keep the film temperatures low. The result is the most forgiving heater on the market.
- The heater has a 20" bolted man-way. This allows access to the radiant section without removing the cover, the burner, the fuel train, the can and the conduit. This internal inspection is required in most states.
- The heater coil does not have an internal can welded to the coil which makes on-site coil replacement impossible.
- The heater comes standard with two (2) peep sights. One is located in the burner to allow the flame mixing to be observed. Another is provided in the cover opposite the burner to enable one to observe the flame pattern and ensure there is no flame impingement on the heater coil.
- Insulation is on the inside of the heater where it will not be damaged during shipment.
- Efficiency of a two pass heater with a convection section will surpass that of a three pass heater.

EQUIPMENT RECOMMENDATIONS:

(2) TWO PASS THERMAL FLUID HEATER:

Heater proper

- Carbon Steel
- 150 # flanges on inlet and outlet nozzles
- Heater coil hydro-testing per ASME code
- Coil will be stamped and receive National Board registration
- carbon steel shell and bolted end covers (w/ lift eyes).
- Ceramic fiber blanket insulation applied to the interior of heater shell and covers.
- Rear cover peep sight
- Structural steel skid with saddles welded to channels to form a skid mounted frame
- Skid lifting lugs
- Stack with flanged bottom connection, rain cap and bird screen mounted on top of the heater, insulated

Bloom Engineering Low NOx Burner for Natural Gas combustion

- Direct spark ignited natural gas pilot (Interrupted type) with ignition transformer
- Self checking UV Flame detection scanner for proving main and pilot flames
- Combustion air blower with duct, damper, locally mounted low combustion air switch and modulation motor containing low / high fire proof switches
- Silencer for 85 dBA
- Using FGR technology
- (Non-API) Robinson Blower
- Fuel train typically includes the following (actual items will change as required by insurance parameter stated on page 2, i.e. FM, IRI, etc.):
 - Pilot train with regulator, safety shutdown valve, manual valve, and pressure gauge with isolation valve
 - Main train with regulator, safety shutdown valve with proof of closure switch, locally mounted high and low pressure switches, two (2) manual valves, fuel modulation valve mechanically with ratio-matic regulator, pressure gauge with isolation valve

The burner emissions guarantee is stated below. Any changes in data or the process variables specific to this application, or failure to comply with any conditions and limits stated below, voids this guarantee.

Emission Guarantees based on HHV:

NOx (lbs/mmbtu – PPM) =

CO (lbs/mmbtu - PPM) =

SOx (lbs/mmbtu - PPM) =

PM (lbs/mmbtu - PPM) =

VOC (lbs/mmbtu - PPM) =

1. All emissions are from to of maximum combustion rating.
2. All emissions in the units of PPM are referenced to ...% dry stack oxygen.
3. Emissions are valid for natural gas (fuel analysis must be submitted by customer) combustion only. The values are based on natural gas containing no bound nitrogen and no sulfur
4. If the stack emissions exceed the guarantee level, the proposed company / Burner manufacturer will work with customer to reduce the emissions to the guaranteed level. The proposed company

- / Burner manufacturer will, at its costs, make any and all adjustments and / or modifications to burner that it deems appropriate and proper to meet required levels.
5. Compliance testing of the system must be conducted within 60 days of initial start-up. Start-up must occur no later than 120 days from shipment. Testing is to be accomplished by an independent authorized agency agreed to by the proposed company / burner manufacturer utilizing EPA-Method 7E. All costs of compliance testing shall be paid by customer.
 6. All guarantees contained in these conditions and limits shall end following completion of compliance testing wherein all emission test points are documented to be at or below guaranteed levels.

Electrical Control Panel Built to NEC requirements and U.L. listed NEMA 4 S.S. (Optional NEMA 4x w/Z-purge)

- Panel door disconnect switch with external operating handle
- Heated and cooled
- Window Kit
- Yokogawa UT-350 Controls for Remote Operation Temperature Control.
- Honeywell E-300 First out Annunciator
- Insulated Panel
- Motor starter protectors (breaker, overload and contactor) for blower motor
- Burner management system (B.M.S.) (U.L. listed as required by NFPA)
- First out annunciator
- Step-down transformer for 120 volt control circuitry
- Control relays and numbered terminal strips with enclosed wiring raceways
- Yokogawa temperature controller (digital) with remote set-point capability (4-20 mA signal)
- Yokogawa high fluid and stack temperature limit switches (digital) each with manual reset and each with remote output capability (4-20 mA signal)
- Lights for: power on, ignition, main fuel, blower on, burner on and alarm silenced
- Switches for: burner off/on, alarm silence, and low fire hold
- Flame safety reset button
- Alarm horn, to indicate alarm (mounted adjacent to panel)

GAS TRAIN: ANSI 150# RF Flange

- Pilot train with regulator, electric double block & bleed safety shutdown valves, manual valve, 1 x pressure gauge
- Main train
 - Drip leg
 - NEMA 7
 - Pneumatic for -40°F Operation
 - Manual shutoff valve
 - Gas Strainer
 - Tee to pilot train
 - Pressure gauge x 2
 - Gas regulator (Must be vented to a safe location)
 - Vent line with manual shutoff valve for leak testing
 - Low and high pressure switches Leakage test connection with manual shutoff valve
 - Fuel Modulation via Ratiomatic regulator or mechanical linkage to damper modulation motor
 - Double block (one with proof of closure switch) safety shutdown valves

- Safety vent valve. Bleed line with two (2) manual shutoff valves for leak testing
- 30% Radiographed
- 30% Dye Penetrant

Locally mounted instruments:

- Low pressure switch (Diaphragm Type) for low thermal oil flow shutdown
- High pressure switch (Diaphragm Type) for high thermal oil pressure shutdown
- Inlet / outlet thermal oil pressure gauge with shut off cock and
- Inlet / outlet thermal oil thermometer with thermo-well
- Stack and thermal oil outlet thermocouples
- Thermal oil pressure relief valve connection. (NON-API) Relief valve is included.
- Galvanized rigid conduit is utilized for wiring. Flex conduit is kept to a minimum.

Pump Assembly

- All Testing and Certification
- Including Flex Hoses on the Primary line
- Starter and Switches for the Pump
- Skid Mounted
- Pressure Transmitters (Rosemount)
- Pressure Indicator

Air Separator:

- All Piping to Pump Package
- Check Valves
- Temperature Control
- Drain Piping

Additional Adders Included:

- 8' Exhaust Stack Insulated
- Complete Heater Environmental Enclosure to cover the fuel train, burner, and control panel. Includes service light, hinged doors, electrically heated, and insulation.
- Optional Hydrocarbon Detector
- Provisions for Customer Supplied Heat Sensor Connections
- (5) Pressure Transmitters for the thermal heater
- (2) Pressure Transmitter for the pumps
- (4) Temperature Transmitters for the heater
- Profiler

DRAWINGS / ENGINEERING:

Drawing period is based on current engineering load and is subject to change without notice. Drawings will be sent via e-mail or provided on disk (ACAD 2010). Please note that the tolerance of our drawings

is + or $-\frac{1}{4}$ ". Construction of connections to heater should allow for modifications to be made in the field with at least 2 degrees of freedom.

Our quotation is in basic accordance with the specifications, drawings, terms and conditions, and requirements of the invitation to bid; however, the following exceptions have been identified, priced and are attached hereto for consideration

Purchase order must make reference to The proposed company quotation
Equipment is quoted FCA, The proposed company, Chattanooga; TN. Equipment will be loaded on truck free of charge. This means the delivery of equipment on the truck at the specified point of departure (The proposed company) is covered in the quotation price. Customer is responsible for the main carriage / freight, cargo insurance and other costs and risks. The purchaser shall furnish all necessary facilities, labor, materials and equipment for unloading and conveying the equipment to its erection point. The equipment shall be erected, installed, set and leveled by the purchaser at its expense. Purchaser shall furnish all necessary labor, materials, equipment, fuel, inert snuffing controls / media, air (if required), nitrogen (if required) and electricity required for starting up the equipment. The proposed company will not be responsible for the installation or design of the footings, foundations or anchor bolts. Emissions compliance testing, mechanical run test and performance tests are not included in quotation. Testing included in quote includes the testing as described in the proposed company Standard FAT (Available for inspection) and the proposed company Standard ITP (Available for inspection) and any tests stated in the quote.
Internally insulated with ceramic fiber blanket insulation. Blanket is held in place with 310 SS pins and washers which are welded to the shell and end plates.
The proposed company warranty, guarantee, payment terms and cancellation Charges are as stated below.
Export packing / preservation / storage are not included. Domestic packing is included. This includes flange / stack covers, wrapping of panel, crating of loose shipped parts.
Taxes, tariffs and duties are not included. Order will be executed according to USA / TN laws. It is the responsibility of the purchaser to inform us via specifications of local / jurisdictional laws that may affect equipment design (i.e. emissions, insurance codes, etc.). Purchaser assumes all responsibility for complying with all federal, state and local statutes, laws, codes, regulations and ordinances in connection with the design, installation and operation of the equipment and any other activity related thereto, including, without limitation, the Environmental Protection Act and all rules and regulations promulgates there-under and the Occupational Safety and Health Act and all rules and regulations promulgates there-under. Some parts of the heater will exceed OSHA temperature requirements. (Average skin temperature of heater shell is 170°F with 5 mph wind

and 70°F ambient.)
All drawings will be standard AUTO-CAD 2010. Delivery time stated in quote depends upon the approval process and the changes made during this process. Typical approval time is two weeks after receipt on all drawings. Only those drawings listed above will be offered. Drawings will be submitted electronically. If drawing approval consists of multiple or major changes delivery time can be affected as well as the price. Drawing period is based on current engineering load and is subject to change without notice. Drawings will be sent via e-mail or provided on disk. <u>Hard copies will require additional cost.</u> Please note that the tolerance of our drawings is + or - 1/4". Construction of connections to heater should allow for modifications to be made in the field with at least 2 degrees of freedom.
Control voltage is as stated in quotation.
Insulation / tracing / personnel protection of piping and equipment external of heater is not included. This is best done in the field by local contractor to eliminate damage during shipment and to allow checking for leaks prior to start up.
Fusible loop system, testing of refractory / insulation materials, burner / blower testing, spreader bar and slings are not included.
Galvanic isolation barriers and cathodic protection are not included.
Single line drawings are not included. The proposed company performs ladder type diagrams.
Pipe, fittings, bolts, nuts and steel will be purchased from The proposed company 's standard vendors. Plate and shapes are A36 carbon steel. Tubes supports are 304 SS. Stud bolts are SA 193 Br B7. Nuts are SA 194.
All purchased items will remain as painted from respective vendor.
Ladders and platforms are not included unless stated in quote.
If area is Class I Div 2 then panel is NEMA 4X with "Z" type purging. All other controls are NEMA 7, hermetically sealed, intrinsically safe or they are purged. Motors are TEFC. Equipment will be designed to NEC area as stated in quote.
The proposed company standard Quality control manual will be used for all welding, NDE, etc. The proposed company standard welding procedures will be used for all welding. The proposed company, Inc. weld procedures and welders are ASME approved/certified. The weld procedures

<p>are available for customer review only and revisions are not allowed. If customer specifications have requirements other than what is listed on The proposed company, Inc. weld procedures, then customer specific weld procedures can be produced. New procedures will result in a cost adder and will delay the original shipping date provided in the proposed company, Inc. quote. The increase in cost and length of delay will be dependent on the extent of the specification requirements. NDE of non-pressure vessel welds is not included unless stated in quote. Non pressure vessel welds are continuous but are not full penetration.</p>
<p>Flame arrestor, spark arrestor, UPS, noise test, fire & gas detection, outdoor lights, aviation lights, variable speed motors, soot blowers, lancing ports, fireproofing, knockout tank, insulation rings, insulation clips, vapor barriers, explosion door, spare parts, thermal fluid, shell / structural / piping stress analysis test, export custom clearance and vibration tests, start-up and erection assistance are not included.. Only the controls listed in the quote are provided.</p>
<p>Hazardous area electrical equipment certification is simply a copy of each electrical item certificate. The entire heater does not have this type of approval.</p>
<p>Liquidated damages shall not apply.</p>
<p>The proposed company , Inc. takes exception to specifications and required documentation referring to any other language other than English.</p>
<p>The proposed company , Inc. is not responsible for implementing documentation relating to exporting/importing proposed equipment into any country outside the Continental United States</p>
<p>Seal offs (If required) are to be poured in the field by customer.</p>
<p>Relief valves and vents should be piped to a safe location by customer.</p>
<p>Noise data sheet is provided by the blower manufacturer only</p>
<p>Pumps and blower are not API type</p>
<p>Redundancy is not included.</p>
<p>Thermal fluid by-pass, releif valve by-pass, reflief valve isolation and flow control is not included unless specifically stated in the quote.. By-pass and isolation valves around flow control valves and regulators have not been included.</p>
<p>Shield rows in convection section are not required or included.</p>
<p>SAT / Performance test is not included. Functional test of all components is included.</p>
<p>Skid drip pan, lip and grating have not been included.</p>

Rupture discs are not included on relief valves.
Galvanizing of any materials is not included unless stated in quote.
PWHT is not included.
Relief valves are ASME Section VIII type

Taxes:

All taxes that the company may be required to pay to any government (foreign, federal, state or municipal) will require reimbursement.

Pricing validity:

The proposed company retains the right during this period to change prices due to the high volatility of steel prices and the rapidly changing cost of materials in today's market place. Any order will be subject to a review of material costs from the time of the proposal to the time of the order received. Any cost changes will be validated to the Customer to provide evidence of what changed which may affect the proposed company's acceptance or rejection of the order or cause a cost change to the Customer for an accepted order. We regret that this review is necessary; however, most material costs are spot costs in this time of scarce resources.

Delivery:

Delivery period is based on current manufacturing load and is subject to change without notice. Long lead items will need to be ordered prior to approvals in order to meet the quoted delivery date. If any of these items are changed during the approval process charges may result for restocking. Provided, however, that if Purchaser is in default of any kind of its obligations under this proposal, Company may, at its election, withhold any further performance of its obligations and duties under this proposal until such time as such default has been cured by the Purchaser, in which event the anticipated date of shipment as set forth herein shall be adjusted accordingly. The Company shall not be liable or responsible for, nor shall the contract price, stated herein, be reduced by any amount because of any matters beyond the control of the Company which delay or postpone the anticipated date set forth above for the delivery of the equipment, such matters including, but not limited to, warlike acts, civil disorder, governmental restriction, acts of God, prior sale, acceptance of United States government

contracts, strike, lockout, accidents, freight embargo, fire, flood, inability of the Company to obtain necessary materials, supplies, labor or transportation, or any unforeseen water, soil or rock conditions.

A detailed shipping list will accompany the bill of lading and Purchaser agrees to check the equipment as it is unloaded and any claim for shortage against The proposed company will be made in writing within 24 hours of the time of unloading. Claims for loss in transit will be made against the carrier by the Purchaser and not against the proposed company.

Terms of payment:

Purchaser shall pay the purchase price in progress payments as follows:

*Receipt of these progress payments is required before the equipment will be released for shipment.

*...% Down-payment with PO

*...% on issue of approval drawings

*... % on coil hydro-test

*... % on ready to ship

Electronic Transfer required 15 days after invoice receipt

Refundment / security / performance bonds are not included.

Purchaser agrees that in the event any amount payable by it to The proposed company under the terms of this agreement remains unpaid for more than 15 days, a service charge of 1.5% per month shall accrue on such unpaid amount beginning on the first day after such late payment is due. If the indebtedness, including service charges, is placed in the hands of an attorney for collection, or is collected through an attorney, Purchaser will pay all costs of collection, including court costs and reasonable attorneys' fees.

Nozzle loadings:

Heater only: External (customer) piping, ductwork etc. not to impose any loads to nozzles-/connections of the proposed company equipment. In case of reactions from piping that cannot be compensated externally to The proposed company equipment, contact The proposed company Engineering.

Responsibility for the operation of the equipment:

The operation of the equipment both prior and subsequent to the Acceptance Period shall be the sole and exclusive responsibility of Purchaser. Any assistance rendered by the Company's representatives during the Acceptance Period in connection with the preliminary operations and demonstrations of capacity and performance of the equipment or in any other capacity shall be given solely in a consulting or advisory capacity and shall not release Purchaser in any manner whatsoever from its responsibility for operating the equipment. Purchaser agrees to indemnify and hold harmless the Company and all employees of the Company from and against all liabilities, damages, obligations and claims (including, without limitation, court costs and reasonable attorneys' fees) arising from or with respect to the operation of the equipment. Without limiting the generality of the preceding sentence, the parties acknowledge and agree that if a claim initially was brought against the Company for defective manufacture, design or the like and was finally determined by a court of competent jurisdiction or otherwise settled (such settlement being with Purchaser's consent) on a basis relating to the negligent operation or use of the equipment, Company would be entitled to indemnification pursuant to the provisions of the preceding sentence.

Insurance:

Until the equipment is accepted and the price is paid in full, the Purchaser shall provide and maintain insurance to the total value of the equipment delivered hereunder against customary casualties and risks, including fire and explosion, and shall also insure against liability for accidents or injuries to the public or to employees, in the names of the company and the Purchaser, as their interests may appear, and in amounts satisfactory to Company. If the Purchaser fails to provide such insurance, it then becomes the Purchaser's responsibility to notify the Company so that the Company may provide

same, and the cost thereof shall be added to the contract price. All loss resulting from failure to affect such insurance shall be assumed by the Purchaser.

Maintenance & Operating Computer Disc Guides:

The proposed company Inc. will supply four (4) copies of the guides on compact disc with the unit. Any additional copies will be an extra expense of \$..... each. If manuals are not received with equipment shipped, contact factory immediately.

Guarantee:

The Company (THE PROPOSED COMPANY, INC.) guarantees to the original purchaser only that the equipment quoted on the above subject quotation will perform at its rated capacity as indicated on this quotation when properly installed, connected, and correctly operated and maintained. Where this equipment is merely a part of a whole system, the Company can only accept responsibility for performance of equipment furnished by it. Due to the nature, use and operation of fuel fired equipment, its controls and accessories; there is a possibility of explosive hazard. In order to avoid such hazard, it is urged that this equipment be installed, operated, and maintained in accordance with guides furnished and safe plant maintenance procedures.

Performance:

The performance of the equipment covered in this proposal cannot be exactly predicted for every operating condition. In consequence, any predicted performance data submitted is intended to show probable operating results which may be closely approximated, but which cannot be guaranteed except as expressly stated in the warranty clause herein

Weld Procedures Note:

The proposed company, Inc. weld procedures and welders are ASME approved/certified. The weld procedures are available for customer review only and revisions are not allowed. If customer specifications have requirements other than what is listed on the proposed company, Inc. weld procedures, then customer specific weld procedures can be produced. New procedures will result in a

cost adder and will delay the original shipping date provided in the proposed company, Inc. quote. The increase in cost and length of delay will be dependent on the extent of the specification requirements.

THE PROPOSED COMPANY WARRANTY

The proposed company, a subsidiary of Astec Industries, warrants each new piece of equipment or part manufactured by us to be free from defective material and workmanship for its normal use and service. We warrant our equipment and parts for a period of one year after shipment of such equipment to the original purchaser. However, if purchaser requests delayed shipment when notified that the equipment is ready to ship, warranty is from time of first notification.

Our obligation under this warranty is limited to replacing defective parts at our factory. Defective parts must be returned to our factory with transportation charges prepaid. We will replace only those parts that we judge, as a result of examinations we make at the factory, to be defective. Exceptions to the warranties are as follows:

- The proposed company warrants helical coils in our HCS and HCI *thermal fluid* heaters for three years.
- The proposed company warrants helical coils in our HC and HCM heaters for five years.
- The proposed company makes no warranty on refractory materials.

We do not warrant any equipment that has, in our judgment, been repaired or altered outside our factory in a way that affects its stability or reliability. Neither do we warrant any equipment that has been misused, neglected, accidentally damaged, or subjected to conditions contrary to our recommendations.

Parts and equipment produced by other companies are covered by separate warranties from their manufacturers. Such items include motors, motor starters, pumps, mixers, mills, scales, pump seals, speed reducers, valves, pressure regulators, solenoids, electronic drives, pressure differential switches, temperature sensing switches, flame scanners, gauge boards, modulating actuators, electronic displays, pressure transmitters, radar sensors and other electronic controls and

instrumentation. Because such items are covered by separate warranties they are not included in the proposed company warranty. We reserve the right to change or improve our products at any time without any obligation to make changes or improvements to equipment previously sold.

This warranty is expressly in lieu of any other warranties, including any implied warranty of merchantability or any implied warranty of fitness for a particular purpose on any product manufactured by the proposed company. The proposed company shall not be liable for any consequential damages for breach of any written or implied warranty on any of our products.

Law controlling:

This instrument and all questions regarding the performance of the parties hereunder shall be controlled by the laws of the State of Tennessee. Purchaser hereby agrees that suit on this contract or on any of the indebtedness secured under this contract may be brought in any State or Federal Court having jurisdiction over the person or any property of Purchaser and in any event in any State or Federal Court or located in the State of Tennessee, and Purchaser irrevocably covenants and agrees to waive any objection to jurisdiction or any such court and affirmatively consents and agrees to the jurisdiction of any such court, and appoints the Secretary of State of Tennessee, as agent for service of process on the Purchaser in the State of Tennessee.

Cancellation Charges:

30 days AOA-----20% of total

60 days AOA-----30% of total,

Plus any cancellation or restocking charges from sub vendors

90 days AOA-----Minimum of 50%, plus any cancellation or restocking charges from sub vendors, plus cost of any non-returnable items. Non-returnable items become the property of the purchaser and delivered F.O.B. from site location.

Startup Service:

Startup service is not included in quotation unless it is listed in the quote or in the options. A separate purchase order must be issued for this service. Two weeks' notice is required for this service. Please see attached "Industrial Service Charges, Terms & Conditions" for rates.

Proposal/PO Disclaimer Statement:

Should a purchase order be awarded to the proposed company, only those specifications received before quotation issue date will be considered valid. Any additional or different specifications included in body of purchase order, or attached to, or otherwise included with said purchase order, will be reviewed for possible additional pricing/delivery and/or design changes.

INDUSTRIAL SERVICE CHARGES, TERMS & CONDITIONS

For service in all 50 states and Canada

	Travel Time	Labor Rate	Overtime Labor Rate
Monday through Friday**			
Saturdays & Overtime*			
Sundays and Holidays			

*Regular time is eight work hours per/day, overtime is any time over eight work hours per/day.

**Excludes holidays.

For International Field Service Work: The following rates are net charges in U.S. funds and are not subject to discounts.

(All locations not included above or listed below)

	Travel Time	Labor Time*	Overtime Labor Rate
Monday through Friday**			
Sat., Sun., and Holidays			

For Offshore Coastal U.S. Field Service Work

	Travel Time	Labor Rate*	Overtime Labor Rate
Monday through Friday**			
Saturdays & Overtime			
Sundays and Holidays			

a) Charges are Portal to Portal. Travel time will be invoiced at the Travel Rate of the day traveled. Travel time will be based on published times & miles (mapquest.com) from Chattanooga, TN to job site. Minimum invoice will be one day. Any Standby Time will be invoiced at the Standard Labor Rate of the day it occurs. Time required for obtaining foreign travel visas, permits or inoculations will be invoiced at the Standard Rates. All related expenses will be invoiced at cost. Work or travel before 8:00 a.m. or after 5:00 p.m., whether eight (8) hours have been used or not, will be billed at 1.5 times the day rate not to exceed Sunday rate. Work or travel done over twelve (12) hours will be billed at two (2) times the applicable hourly rate.

b) Air Travel is Tourist Class. Air travels over hrs on any one flight is Business Class. Expenses for air travel, car rental, taxi, lodging, meals, and miscellaneous will be invoiced at cost. Auto mileage of private or company vehicle will be invoiced at \$...../mile.

c) Service Personnel are insured. Certificates of Insurance and Workman’s Compensation are available upon request. Service Personnel will not work unassisted without qualified customer personnel on location for assistance.

d) A purchase order or authorization by an authorized company representative is required for Domestic Service and a Letter of Credit for International service.

e) Payment is due upon receipt of invoice.

f) On acceptance or payment of the proposed company’s services, the customer releases the proposed company and the technician/engineer from any and all claims arising as a result of the services rendered.

g) The proposed company will not be liable for damages to the customer’s plant or loss of product, damage to equipment, materials or consequential damages of any kind in execution of service, consultation, inspection, start-up, troubleshooting, technical installation or repair, maintenance, testing and training of personnel.

h) Rates are subject to change without notice.

Appendix D

MATLAB Code for the Value Packaging System

This appendix includes MATLAB code for the value packaging system presented in Chapter 5 of this thesis.

Rerun Loop:

```
finalcell = cell(10000,length(contrac(1).weightedmat));
finalvect = struct('a',zeros(1000,1));

for j = 1:10000
vuvector = 1:1:length(contrac(1).weightedmat);
vuvector = vuvector(randperm(length(vuvector)));
vpvect = struct('mat1',zeros(1,3),'contr',cell(1,3),'mat2',zeros(1,3));
valpackages = zeros(1,length(contrac(1).weightedmat));
valpackagecap = zeros(1,3);
valpackagecap(1) = randi([0 length(contrac(1).weightedmat)]);
boolval = false;
while boolval == false
    valpackagecap(2) = randi([0 length(contrac(1).weightedmat)]);
    if sum(valpackagecap) > length(contrac(1).weightedmat)
        continue
    elseif sum(valpackagecap) == length(contrac(1).weightedmat)
        break
    elseif sum(valpackagecap) < length(contrac(1).weightedmat)
        valpackagecap(3) = length(contrac(1).weightedmat) -
sum(valpackagecap);
        boolval = true;
    end
end
lastindex = [0 0];

for i = 1:length(valpackagecap)
    if valpackagecap(i) > 0 & lastindex(1) == 0
        lastindex(1) = valpackagecap(i);
        vpvect(i).mat1 = zeros(1,valpackagecap(i));
        vpvect(i).mat2 = zeros(1,valpackagecap(i));
        vpvect(i).mat1 = vuvector(1:lastindex(1));
    elseif valpackagecap(i) > 0 & lastindex(1) ~= 0
        lastindex(1) = lastindex(1)+1;
    lastindex(2) = valpackagecap(i)+lastindex(1)-1;
    vpvect(i).mat1 = zeros(1,valpackagecap(i));
    vpvect(i).mat2 = zeros(1,valpackagecap(i));
        vpvect(i).mat1 = vuvector(lastindex(1):lastindex(2));
        lastindex(1) = lastindex(2);
    elseif valpackagecap(i) == 0
        vpvect(i).mat1 = [];
```

```

        vpvect(i).mat2 = [];
    end
end
    cmethod = randi([1 tempnum]);
    for i = 1:length(valpackagecap)
        cmethod2 =
find(cellfun(@isempty, strfind({contrac.contractor}, num2str(cmethod))) ==
0);
        cchoose = cmethod2(randi([1 length(cmethod2)]));
        if isempty(vpvect(i).mat1) == 0
            vpvect(i).contr = cell(1, length(vpvect(i).mat1));
            vpvect(i).contr(1:end) = {contrac(cchoose).contractor};
            vpvect(i).mat2 = contrac(cchoose).weightedmat(vpvect(i).mat1)';
        end
    end
end
[~, i] = sort([vpvect.mat1]);
tempvar = [vpvect.contr];
finalcell(j, :) = tempvar(i);
finalvect(j).vpvect = vpvect;
finalvect(j).rating = sum([vpvect.mat2]);
end
exportcell = cell(160, length(contrac(1).weightedmat)+1);
[~, ind] = sort([finalvect.rating], 'descend');
sindex = [1 3 5];
altern = 1;
cntr = 1;
for i = 1:20
    exportcell(altern, 1) = {'Alt_' num2str(cntr)};
    exportcell(altern+1, 1) = {'VP1'};
    exportcell(altern+3, 1) = {'VP2'};
    exportcell(altern+5, 1) = {'VP3'};

    exportcell(altern+3, 2:length(finalvect(ind(i)).vpvect(2).mat1)+1) =
vector2cell(finalvect(ind(i)).vpvect(2).mat1);
    exportcell(altern+5, 2:length(finalvect(ind(i)).vpvect(3).mat1)+1) =
vector2cell(finalvect(ind(i)).vpvect(3).mat1);

    for x = 1:3
        if isempty(finalvect(ind(i)).vpvect(x).contr) == 0

%exportcell(altern+sindex(x), 2:length(finalvect(ind(i)).vpvect(x).mat1)+1)
= vector2cell(finalvect(ind(i)).vpvect(x).mat1);

exportcell(altern+sindex(x)+1, 2:length(finalvect(ind(i)).vpvect(x).mat1)+1)
) = finalvect(ind(i)).vpvect(x).contr;
        for n = 1:length(finalvect(ind(i)).vpvect(x).contr)
            exportcell(altern+sindex(x), n+1) = {'VU'
num2str(finalvect(ind(i)).vpvect(x).mat1(n))}];
        end
    end
end

```



```

        end
    end
    cntr = cntr+1;
    altern = altern + 8;
end
xlswrite('Alternatives_VPs_feb_10_2012_1.xls',exportcell)

```

Value package:

```

valunits = 1:1:10;

valunits = valunits(randperm(length(valunits)));

prompt = {'Please enter the number of methods'};
dlg_title = 'Input Number';
num_lines = 1;
def = {' '};
tempnum = inputdlg(prompt,dlg_title,num_lines,def);
tempnum = cell2mat(tempnum);
tempnum = str2double(tempnum);

waitfor(helpdlg('Please Select the folder of criteria matrices'))
%obtain criteria matrix directory
direct = uigetdir;

%Extract file names onto a cell variable
files = cellstr(ls(direct));
%Filter files to extract only text files
%Use temporary boolean variable
bool = find(cellfun(@isempty,strfind(files, '.xls'))== 0);
files = files(bool);
%Clear Boolean variable
clear bool
%Pre-declare files and contractors variable outside of loop to
%Optimize code execution speed
filemats = cell(1,length(files));
contractors = cell(1,length(files));
for i = 1:length(files);
    %Split the filename string parameters
    params = strsplit(files{i}, '_');
    %store criteria matrix onto variable
    contractors(i) = params(1);
    filemats{i} = xlsread([direct...
    '\ ' files{i}]);
end

```

```

%Create contractor structure containing all VU information
contrac = struct('contractor',contractors,'critmat',filemats);
    waitfor(helpdlg('Please Select the Contractor information Worksheet'))

[temp1 temp2] = uigetfile;
worksheetfile = [temp2 temp1];

weightvect = xlsread(worksheetfile,'weighting_vector');

%Normalize matrix values as well multiply the criteria matrices by the
%weighted vector.
for i = 1:length(contrac)
    contrac(i).critmat = normmatrix(contrac(i).critmat);
    contrac(i).weightedmat = contrac(i).critmat * weightvect;
end

finalcell = cell(1000,length(contrac(1).weightedmat));
finalvect = struct('a',zeros(1000,1));

for j = 1:10000
vuvector = 1:1:length(contrac(1).weightedmat);
vuvector = vuvector(randperm(length(vuvector)));
vpvect = struct('mat1',zeros(1,3),'contr',cell(1,3),'mat2',zeros(1,3));
valpackages = zeros(1,length(contrac(1).weightedmat));
valpackagecap = zeros(1,3);
valpackagecap(1) = randi([0 length(contrac(1).weightedmat)]);
boolval = false;
while boolval == false
    valpackagecap(2) = randi([0 length(contrac(1).weightedmat)]);
    if sum(valpackagecap) > length(contrac(1).weightedmat)
        continue
    elseif sum(valpackagecap) == length(contrac(1).weightedmat)
        break
    elseif sum(valpackagecap) < length(contrac(1).weightedmat)
        valpackagecap(3) = length(contrac(1).weightedmat) -
sum(valpackagecap);
        boolval = true;
    end
end
lastindex = [0 0];

for i = 1:length(valpackagecap)
    if valpackagecap(i) > 0 & lastindex(1) == 0
        lastindex(1) = valpackagecap(i);
        vpvect(i).mat1 = zeros(1,valpackagecap(i));
        vpvect(i).mat2 = zeros(1,valpackagecap(i));
        vpvect(i).mat1 = vuvector(1:lastindex(1));
    elseif valpackagecap(i) > 0 & lastindex(1) ~= 0
        lastindex(1) = lastindex(1)+1;
    end
end

```

```

lastindex(2) = valpackagecap(i)+lastindex(1)-1;
vpvect(i).mat1 = zeros(1,valpackagecap(i));
vpvect(i).mat2 = zeros(1,valpackagecap(i));
vpvect(i).mat1 = vuvector(lastindex(1):lastindex(2));
lastindex(1) = lastindex(2);
elseif valpackagecap(i) == 0
    vpvect(i).mat1 = [];
    vpvect(i).mat2 = [];
end
end
cmethod = randi([1 tempnum]);
for i = 1:length(valpackagecap)
    cmethod2 =
find(cellfun(@isempty, strfind({contrac.contractor}, num2str(cmethod))) ==
0);
    cchoose = cmethod2(randi([1 length(cmethod2)]));
    if isempty(vpvect(i).mat1) == 0
        vpvect(i).contr = cell(1,length(vpvect(i).mat1));
        vpvect(i).contr(1:end) = {contrac(cchoose).contractor};
        vpvect(i).mat2 = contrac(cchoose).weightedmat(vpvect(i).mat1)';
    end
end
[~, i] = sort([vpvect.mat1]);
tempvar = [vpvect.contr];
finalcell(j,:) = tempvar(i);
finalvect(j).vpvect = vpvect;
finalvect(j).rating = sum([vpvect.mat2]);
end
exportcell = cell(160,length(contrac(1).weightedmat)+1);
[~, ind] = sort([finalvect.rating], 'descend');
sindex = [1 3 5];
altern = 1;
cntr = 1;
for i = 1:20
    exportcell(altern,1) = {'Alt_' num2str(cntr)};
    exportcell(altern+1,1) = {'VP1'};
    exportcell(altern+3,1) = {'VP2'};
    exportcell(altern+5,1) = {'VP3'};

    exportcell(altern+3,2:length(finalvect(ind(i)).vpvect(2).mat1)+1) =
vector2cell(finalvect(ind(i)).vpvect(2).mat1);
    exportcell(altern+5,2:length(finalvect(ind(i)).vpvect(3).mat1)+1) =
vector2cell(finalvect(ind(i)).vpvect(3).mat1);

    for x = 1:3
        if isempty(finalvect(ind(i)).vpvect(x).contr) == 0

%exportcell(altern+sindex(x),2:length(finalvect(ind(i)).vpvect(x).mat1)+1)
= vector2cell(finalvect(ind(i)).vpvect(x).mat1);

```

```

exportcell(altern+sindex(x)+1,2:length(finalvect(ind(i)).vpvect(x).mat1)+1
) = finalvect(ind(i)).vpvect(x).contr;
    for n = 1:length(finalvect(ind(i)).vpvect(x).contr)
        exportcell(altern+sindex(x),n+1) = {'VU'
num2str(finalvect(ind(i)).vpvect(x).mat1(n))}];
    end

    end
end
cntr = cntr+1;
altern = altern + 8;
end
xlswrite('Alternatives_VPs_feb_10_2012.xls',exportcell)

```

Normalizing the Matrix Code:

```

function [mat] = normmatrix(mat)
sumcols = zeros(1,size(mat,2));
for i = 1:size(mat,2)
    sumcols(i) = sum(mat(:,i));
    mat(:,i) = mat(:,i)/sumcols(i);
end

end

```

Explanation:

```

function terms = strsplit(s, delimiter)
%STRSPLIT Splits a string into multiple terms
%
% terms = strsplit(s)
% splits the string s into multiple terms that are separated by
% white spaces (white spaces also include tab and newline).
%
% The extracted terms are returned in form of a cell array of
% strings.
%
% terms = strsplit(s, delimiter)
% splits the string s into multiple terms that are separated by
% the specified delimiter.
%
% Remarks
% -----
% - Note that the spaces surrounding the delimiter are considered
% part of the delimiter, and thus removed from the extracted
% terms.
%
% - If there are two consecutive non-whitespace delimiters, it is
% regarded that there is an empty-string term between them.
%
%

```

```

% Examples
% -----
%      % extract the words delimited by white spaces
%      ts = strsplit('I am using MATLAB');
%      ts <- {'I', 'am', 'using', 'MATLAB'}
%
%      % split operands delimited by '+'
%      ts = strsplit('1+2+3+4', '+');
%      ts <- {'1', '2', '3', '4'}
%
%      % It still works if there are spaces surrounding the delimiter
%      ts = strsplit('1 + 2 + 3 + 4', '+');
%      ts <- {'1', '2', '3', '4'}
%
%      % Consecutive delimiters results in empty terms
%      ts = strsplit('C,Java, C++ ,, Python, MATLAB', ',');
%      ts <- {'C', 'Java', 'C++', '', 'Python', 'MATLAB'}
%
%      % When no delimiter is presented, the entire string is considered
%      % as a single term
%      ts = strsplit('YouAndMe');
%      ts <- {'YouAndMe'}
%
%
% History
% -----
%      - Created by Dahua Lin, on Oct 9, 2008
%
%% parse and verify input arguments

assert(ischar(s) && ndims(s) == 2 && size(s,1) <= 1, ...
    'strsplit:invalidarg', ...
    'The first input argument should be a char string.');
```

```

if nargin < 2
    by_space = true;
else
    d = delimiter;
    assert(ischar(d) && ndims(d) == 2 && size(d,1) == 1 && ~isempty(d),
        ...
        'strsplit:invalidarg', ...
        'The delimiter should be a non-empty char string.');
```

```

    d = strtrim(d);
    by_space = isempty(d);
end

%% main

```

```

s = strtrim(s);

if by_space
    w = isspace(s);
    if any(w)
        % decide the positions of terms
        dw = diff(w);
        sp = [1, find(dw == -1) + 1]; % start positions of terms
        ep = [find(dw == 1), length(s)]; % end positions of terms

        % extract the terms
        nt = numel(sp);
        terms = cell(1, nt);
        for i = 1 : nt
            terms{i} = s(sp(i):ep(i));
        end
    else
        terms = {s};
    end
end

else
    p = strfind(s, d);
    if ~isempty(p)
        % extract the terms
        nt = numel(p) + 1;
        terms = cell(1, nt);
        sp = 1;
        dl = length(delimiter);
        for i = 1 : nt-1
            terms{i} = strtrim(s(sp:p(i)-1));
            sp = p(i) + dl;
        end
        terms{nt} = strtrim(s(sp:end));
    else
        terms = {s};
    end
end
end

```

Weighting Vector:

```

function [y] = vector2cell(x)
y = cell(1, length(x));
for i = 1:length(x)
    y(i) = {x(i)};
end
if size(x,1) > size(x,2)
    y = y';
end
end

```

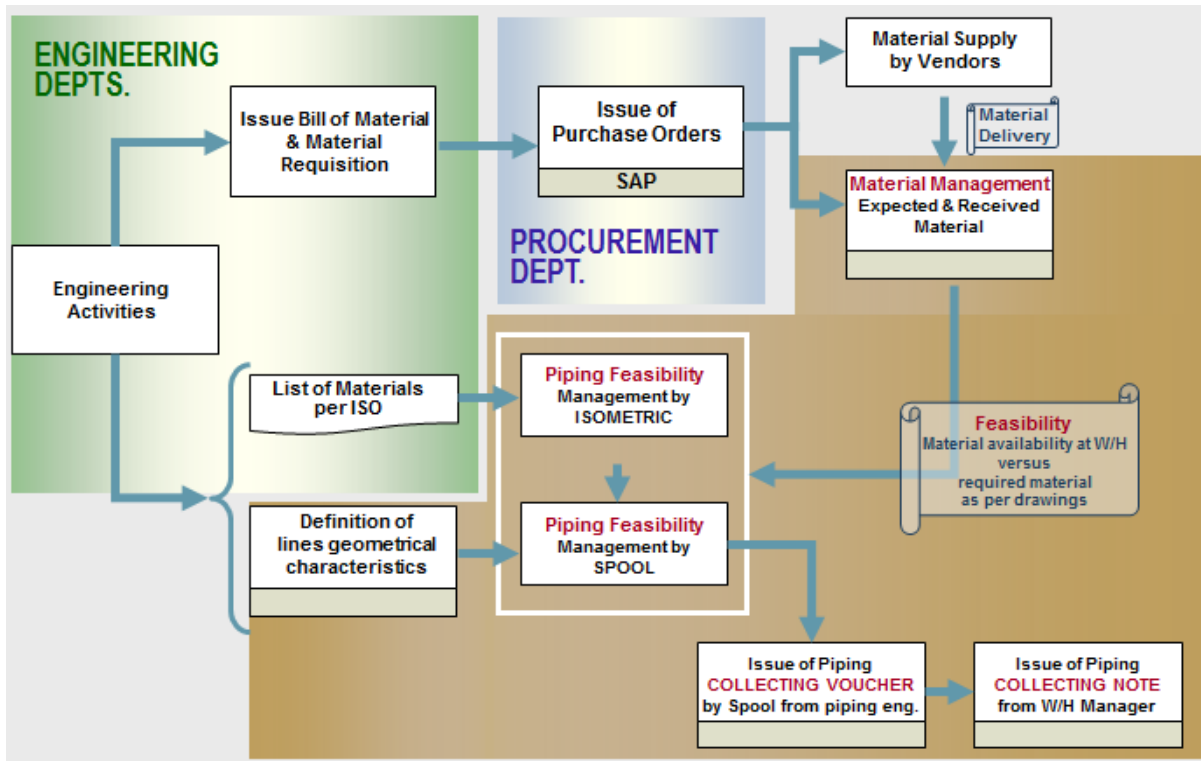
Constraints Matrix:

The screenshot shows the MATLAB Import Wizard interface. The title bar indicates the file path: `C:\Users\User\Desktop\Article and Paper\Jose\Value_Packages_Matlab_March_07\valuepackages_worksheet_feb16_2012.xls`. The 'VIEW' tab is active, showing a range of `B2:C13` and 'Variable Names Row' set to `1`. The 'Import Selection' button is visible on the right. The main window displays a worksheet with the following data:

	A	B	C	D	E
	columnA	MaximumC...	MinimumC...	columnD	Thisworksh...
Cell	Number	Number	Cell	Cell	
1		Maximum ...	Minimum ...		This works...
2	A1	4	0		
3	A2	4	1		
4	A3	4	0		
5	B1	0	0		
6	B2	0	0		
7	B3	0	0		
8	C1	0	0		
9	C2	0	0		
10	C3	0	0		
11	D1	0	0		
12	D2	0	0		
13	D3	0	0		

Appendix E

Subcontractor Material Management System Sample



Appendix F Interface Agreement Form

Title:			
Need Date:			
Response Date:			
Requestor:		Responder:	
Technical Contact:		Technical Contact:	
Discipline:			
Short Description			
Interface Details(Deliverable Description)			
Response			
Requester Documents and References:		Responder Documents and References:	
Attachments:			
Agree & Closed Date:			
Requester:	Date:	Responder:	Date:

Appendix G

Sample of List of Instrument for a Value Package

Tag Number	PID	Service	Line Number	Equip Num	Inst Type	I/O	Remarks
10-PI -0103	PPF0001	NG from BT limit	SNG-10-0001-6"-DD3R61-N		PI		
94-PI -0013	PPF0001	N2 from battery limit	UNLP-94-0009-2"-DD1R61-N		PI		
10-LIT -0111	PPF1001	NG Feed Separator		1001D02	LIT	AI	
10-PSV -0001	PPF1001	Natural Gas feed separator	SNG-10-0013-6"-DD3R61-N		PSV		
10-PSV -0019	PPF1001	NG feed sep to NG trim fuel	UHG-10-0016-4"-DD1R61-N		PSV		
10-PCV -0100	PPF1001	NG Fr feed separator to NG flare header	UGH-10-0237-2"-DD1R79-N		PCV		
10-PIT -0114	PPF1001	NG fr feed sep to feed preheater	SNG-10-0084-6"-DD3R61-N		PIT	AI	
10-PV -0114	PPF1001	NG fr feed sep to feed preheater	SNG-10-0013-6"-DD3R61-N		PV	AO	
10-PN -0114	PPF1001	Solenoid valve for 10-PV-0114			PN	DO	
10-PIT -0144	PPF1001	NG from feed sep to trim fuel preheater	UHG-10-0016-4"-DD1R61-N		PIT	AI	
10-PV -0144	PPF1001	NG from feed sep to trim fuel preheater	UHG-10-0015-4"-DD3R61-N		PV	AO	
10-PN -0144	PPF1001	Solenoid valve for 10-PV-0144			PN	DO	
10-TE -0112	PPF1001	NG feed separator to NG feed gas	SNG-10-0013-6"-DD3R61-N		TE		
10-TT -0112	PPF1001	NG feed separator to NG feed gas	SNG-10-0013-6"-DD3R61-N		TT	AI	
20-FE -0440	PPF1001	H2 recycle to feed gas line	SH2-10-0249-2"-DD3R71-N		FE		
20-FT -0440	PPF1001	H2 recycle to feed gas line	SH2-10-0249-2"-DD3R71-N		FT	AI	
94-PI -0604	PPF1001	N2 to NG feed separator	UNHP-94-0031-4"-DD6R61-N		PI		
10-PT -1801	PPF1003	H2 Product to H2 product compressor	SH2-18-0238-3"-DD3R71-N		PT	AI	Vendor Furnished
10-PT -1804	PPF1003	H2 recycle compressor discharge	SH2-10-0249-2"-DD3R71-N		PT	AI	Vendor Furnished
10-PSV -0002	PPF1006	Hydro-Desulfurization reactor inlet	SSF-10-0278-8"-DG6R79-H4.0"		PSV		
10-PSV -0003	PPF1006	Hydro-Desulfurization reactor Inlet	SSF-10-0278-8"-DG6R79-H4.0"		PSV		
10-PI -0163	PPF1006	Hydro-Desulfurization reactor inlet	SSF-10-0278-8"-DG6R79-H4.0"		PI		
10-PI -0164	PPF1006	Hydro-Desulfurization reactor outlet	SSF-10-0281-8"-DG6R79-H4.0"		PI		
10-PI -0173	PPF1006	Hydro-Desulfurization reactor inlet	SSF-10-0278-8"-DG6R79-H4.0"		PI		
10-PI -0174	PPF1006	Hydro-Desulfurization reactor outlet	SSF-10-0281-8"-DG6R79-H4.0"		PI		
10-TE -0168	PPF1006	Hydro-Desulfurization reactor outlet	SSF-10-0281-8"-DG6R79-H4.0"		TE		
10-TT -0168	PPF1006	Hydro-Desulfurization reactor outlet	SSF-10-0281-8"-DG6R79-H4.0"		TT	AI	

Tag Number	PID	Service	Line Number	Equip Num	Inst Type	I/O	Remarks
10-TE -0178	PFP1006	Hydro-Desulfurization reactor outlet	SSF-10-0281-8"-DG6R79-H4.0"		TE		
10-TT -0178	PFP1006	Hydro-Desulfurization reactor outlet	SSF-10-0281-8"-DG6R79-H4.0"		TT	AI	
10-FE -0120	PFP1007	Feed gas to mixing tee	SSF-10-0018-8"-DG6R79-H4.0"		FE		
10-FT -0120A	PFP1007	Feed gas to mixing tee	SSF-10-0018-8"-DG6R79-H4.0"		FT	AI	
10-FT -0120B	PFP1007	Feed gas to mixing tee	SSF-10-0018-8"-DG6R79-H4.0"		FT	AI	
10-PT -0124	PFP1007	Feed gas to mixing tee	SSF-10-0018-8"-DG6R79-H4.0"		PT	AI	
10-TE -0128	PFP1007	Feed gas to mixing tee	SSF-10-0018-8"-DG6R79-H4.0"		TE		
10-TT -0128	PFP1007	Feed gas to mixing tee	SSF-10-0018-8"-DG6R79-H4.0"		TT	AI	
10-FV -0120	PFP1007	Feed gas to mixing tee	SSF-10-0018-8"-DG6R79-H4.0"		FV	AO	
10-FN -0120	PFP1007	Solenoid valve for 10-FV-0120			FN	DO	
10-FT -0121	PFP1007	N2 During start up mode	SSF-10-0018-8"-DG6R79-H4.0"		FT	AI	
10-FE -0220	PFP1007	Process Steam to mixing Tee	USHP-11-0022-8"-DG6R61-H4.0"		FE		
10-FT -0220A	PFP1007	Process Steam to mixing Tee	USHP-11-0022-8"-DG6R61-H4.0"		FT	AI	
10-FT -0220B	PFP1007	Process Steam to mixing Tee	USHP-11-0022-8"-DG6R61-H4.0"		FT	AI	
10-FT -0220C	PFP1007	Process Steam to mixing Tee	USHP-11-0022-8"-DG6R61-H4.0"		FT	AI	
10-PT -0224	PFP1007	Process Steam to mixing Tee	USHP-11-0022-8"-DG6R61-H4.0"		PT	AI	
10-ZT -0220	PFP1007	Position Xltnr on 10-FV-0220			ZT	AI	
10-FV -0220	PFP1007	Process Steam to mixing Tee	USHP-11-0022-8"-DG6R61-H4.0"		FV	AO	
10-PT -0074A	PFP1007	Process gas to feed superheater	SSFR-10-0021-12"-DG6R79-H4.0"		PT	AI	
10-PT -0074B	PFP1007	Process gas to feed superheater	SSFR-10-0021-12"-DG6R79-H4.0"		PT	AI	
10-PT -0074C	PFP1007	Process gas to feed superheater	SSFR-10-0021-12"-DG6R79-H4.0"		PT	AI	
10-PI -0129	PFP1007	Feed gas to flare system	SSF-10-0019-1"-DG6R79-PP2.5"		PI		
10-PI -0223	PFP1007	Steam to mixing tee	USHP-11-0255-12"-DG6R61-H5.0"		PI		
10-TE -0228	PFP1101	Feed superheater outlet	USHP-11-0022-8"-DG6R61-H4.0"		TE		
10-TT -0228	PFP1101	Feed superheater outlet	USHP-11-0022-8"-DG6R61-H4.0"		TT	AI	
11-AE -0070A	PFP1101	Reformer box O2 Analyzer sensor		1101F01	AE		
11-AT -0070A	PFP1101	Reformer box O2 Analyzer Transmitter		1101F01	AT	AI+2DO	

Tag Number	PID	Service	Line Number	Equip Num	Inst Type	I/O	Remarks
11-LT -0021A	PFP1117	Flue gas steam drum		1102D02	LT	AI	Vendor Furnished
11-LT -0021B	PFP1117	Flue gas steam drum		1102D02	LT	AI	Vendor Furnished
11-LT -0021C	PFP1117	Flue gas steam drum		1102D02	LT	AI	Vendor Furnished
11-LV -0021	PFP1117	BFW to flue gas steam drum	UWBF-12-0060-4"-DD6R61-H3.0"		LV	AO	
11-PSV -0009	PFP1117	Flue gas steam drum		1102D02	PSV		Vendor Furnished
11-PSV -0010	PFP1117	Flue gas steam drum		1102D02	PSV		Vendor Furnished
11-PI -0023	PFP1117	Flue gas steam drum		1102D02	PI		Vendor Furnished
11-PT -0024	PFP1117	Flue gas steam drum		1102D02	PT	AI	Vendor Furnished
11-TE -0028	PFP1117	Steam from Flue gas steam drum	USHP-11-8006-8"-XD6RXX-H4.0"		TE		Vendor Furnished
11-TT -0028	PFP1117	Steam from Flue gas steam drum	USHP-11-8006-8"-XD6RXX-H4.0"		TT	AI	Vendor Furnished
11-PT -0033	PFP1201	Pr Gas to HT-SR	SSG-11-0072-14"-DG6R79-H5.0"		PT	AI	
12-PSV -0021	PFP1201	Pr Gas to HT-SR	SSG-11-0072-14"-DG6R79-H5.0"		PSV		
12-PT -0034	PFP1201	Pr Gas from HT-SR	SSG-12-0073-14"-DG6R79-H6.0"		PT	AI	
12-TE -0031	PFP1201	HT Shift reactor		1203R01	TE		
12-TT -0031	PFP1201	HT Shift reactor		1203R01	TT	AI	
12-TE -0032	PFP1201	HT Shift reactor		1203R01	TE		
12-TT -0032	PFP1201	HT Shift reactor		1203R01	TT	AI	
12-TE -0038	PFP1201	HT Shift reactor outlet	SSG-12-0073-14"-DG6R79-H6.0"		TE		
12-TT -0038	PFP1201	HT Shift reactor outlet	SSG-12-0073-14"-DG6R79-H6.0"		TT	AI	
11-LV -0011	PFP1202	BFW to process gas steam drum	UWBF-12-0060-4"-DD6R61-H3.0"		LV	AO	
12-HV -0275A	PFP1202	Process gas from CHE to process gas cooler	SSG-12-0075-10"-DA6R61-PP4.0"		HV	AO	
12-HV -0275B	PFP1202	CHE bypass pr-gas to pr-gas air cooler	SSG-12-0073-14"-DG6R79-H6.0"		HV	AO	
12-LI -0270	PFP1202	CHE Level		1201D02	LI		
12-LT -0271A	PFP1202	CHE condensate level		1201D02	LT	AI	
12-LT -0271B	PFP1202	CHE condensate level		1201D02	LT	AI	
12-LT -0271C	PFP1202	CHE condensate level		1201D02	LT	AI	
12-LV -0271	PFP1202	CHE condensate to deaerator	SPC-12-0121-4"-DA3R61-H2.5"		LV	AO	

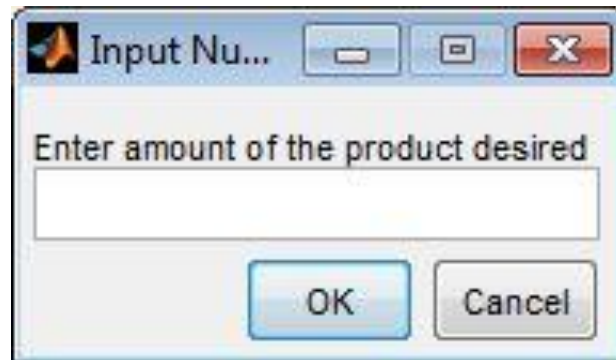
Tag Number	PID	Service	Line Number	Equip Num	Inst Type	I/O	Remarks
12-TE -0058C	PFP1204	Process gas to PSA	SSG-12-0138-10"-DD3R71-HE3.0"		TE		
12-TT -0058C	PFP1204	Process gas to PSA	SSG-12-0138-10"-DD3R71-HE3.0"		TT	AI	
12-XV -0044	PFP1204	Process condensate separator outlet	SPC-12-0137-4"-DA3R61-H2.5"		XV	DO	
18-FIS -0160	PFP1801	N2 Purge	UNLP-18-150-1"-DD1R61-N		FI	DI	
18-PT -0084	PFP1801	Process gas to PSA	SSG-12-0138-12"-DD3R71-H3.0"		PT	AI	
18-PT -0210	PFP1801	PSA purge gas drum to flare	SPP-18-0080-20"-DD1R61-N		PT	AI	
18-PV -0210	PFP1801	PSA purge gas drum to flare	UFGA-18-0147-10"-DD1R79-N		PV	AO	
18-PSV -1004	PFP1801	PSA Purge Gas buffer vessel	SPP-18-0144-20"-DD1R61-N		PSV		Vendor Furnished
18-FE -0300	PFP1802	H2 Product	SH2-18-0156-8"-DD3R71-N		FE		
18-FT -0300	PFP1802	H2 Product	SH2-18-0156-8"-DD3R71-N		FT	AI	
18-TE -0308	PFP1802	H2 Product	SH2-18-0156-8"-DD3R71-N		TE		
18-TT -0308	PFP1802	H2 Product	SH2-18-0156-8"-DD3R71-N		TT	AI	
18-PSV -0013	PFP1802	H2 product	SH2-18-0149-8"-DD3R71-N		PSV		
18-PSV -0014	PFP1802	H2 product	SH2-18-0156-12"-DD3R71-N		PSV		
18-PT -0304	PFP1802	H2 Product	SH2-18-0156-8"-DD3R71-N		PT	AI	
18-PV -0304	PFP1802	H2 product to flare	SH2-18-0156-6"-DD3R71-N		PV	AO	
18-PDI -0360	PFP1802	Product filter DP		1801S01	PDI		
18-FE -0122	PFP1803	Import / Export H2 to product line	SH2-18-0243-8"-DD3R71-N		FE		
18-FT -0122	PFP1803	Import / Export H2 to product line	SH2-18-0243-8"-DD3R71-N		FT	AI	
18-PT -0121A	PFP1803	Import / Export H2 to product line	SH2-18-0243-8"-DD3R71-N		PT	AI	
18-PT -0121B	PFP1803	Import / Export H2 to product line	SH2-18-0243-8"-DD3R71-N		PT	AI	
18-FV -0122	PFP1803	Import / Export H2 to product line	SH2-18-0243-8"-DD3R71-N		FV	AO	
18-FN -0123	PFP1803	Solenoid valve for 18-FV-0122			FN	DO	
20-PT -0444A	PFP2001	Compressed H2 product to battery	SH2-20-0163-6"-DD8J66-N		PT	AI	
20-PT -0444B	PFP2001	Compressed H2 product to battery	SH2-20-0163-6"-DD8J66-N		PT	AI	
20-PV -0444	PFP2001	Compressed H2 product to battery	SH2-20-0163-6"-DD8J66-N		PV	AO	
20-PT -2112	PFP2001	H2 product inlet to H2 product compressor	SH2-18-0156-12"-DD3R71-N		PT	AI	

Appendix H

Graphical User Interface (GUI) for the Material Management System Software

This appendix provides a step-by-step representation of the Graphical User Interface (GUI) of the “ICMM” software that was developed for this research. This software was coded completely in MATLAB environment. Appendix I presents the entire code for this software. The GUIs are depicted in following Figures:





Appendix I

MATLAB Code for the Material Management System

This appendix includes MATLAB code for the data fusion processes presented in Chapter 6 of this thesis. This appendix includes the code related to the Graphical User Interface (GUI), presented previously in Appendix H, and the code related to the MATLAB functions that were programmed for BOM optimization processes.

```
function varargout = bom_initialgui(varargin)
% BOM_INITIALGUI M-file for bom_initialgui.fig
%     BOM_INITIALGUI, by itself, creates a new BOM_INITIALGUI or raises
the existing
%     singleton*.
%
%     H = BOM_INITIALGUI returns the handle to a new BOM_INITIALGUI or
the handle to
%     the existing singleton*.
%
%     BOM_INITIALGUI('CALLBACK', hObject,eventData,handles,...) calls the
local
%     function named CALLBACK in BOM_INITIALGUI.M with the given input
arguments.
%
%     BOM_INITIALGUI('Property','Value',...) creates a new BOM_INITIALGUI
or raises the
%     existing singleton*. Starting from the left, property value pairs
are
%     applied to the GUI before bom_initialgui_OpeningFcn gets called.
An
%     unrecognized property name or invalid value makes property
application
%     stop. All inputs are passed to bom_initialgui_OpeningFcn via
varargin.
```



```

%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only
one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help bom_initialgui

% Last Modified by GUIDE v2.5 27-Mar-2012 14:08:20

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',  gui_Singleton, ...
                  'gui_OpeningFcn', @bom_initialgui_OpeningFcn, ...
                  'gui_OutputFcn',  @bom_initialgui_OutputFcn, ...
                  'gui_LayoutFcn',  [] , ...
                  'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before bom_initialgui is made visible.
function bom_initialgui_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure

```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% varargin command line arguments to bom_initialgui (see VARARGIN)

% Choose default command line output for bom_initialgui
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes bom_initialgui wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = bom_initialgui_OutputFcn(hObject, eventdata, handles)
% varargout cell array for returning output args (see VARARGOUT);
% hObject handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject handle to pushbutton1 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
mkdir('BOM_optimization_output')
activedir = cellstr(ls);
bool = isempty(find(cellfun(@isempty,...
    strfind(activedir,'BOM_database')== 0));
if bool == 1

```

```

I = menu('No BOM database was detected, would you like to create
one?', 'Yes', 'No');

if I == 2
    close(handles.figure1)
end
counter = 0;
while I == 1

counter = counter + 1;

direct = uigetdir;

%Extract file names onto a cell variable
files = cellstr(ls(direct));
%Filter files to extract only text files
%Use temporary boolean variable
bool = find(cellfun(@isempty, strfind(files, '.xls'))== 0);
files = files(bool);
%Clear Boolean variable
clear bool
%Pre-declare dates variable outside of loop to
%Optimize code execution speed
itembom =
struct('itemname', cell(1, length(files)), 'version', cell(1, length(files)));
%Initiate loop to extract dates from file names
%Within the 'files' variable
for i = 1:length(files);
    %Split the filename string parameters
    params = strsplit(files{i}, '_');
    %store date parameter onto variable
    itembom(i).itemname = params(1);
    itembom(i).version = params(2);
end

```

```

    for i = 1:length(files);
        itembom(i).BOM = processBOM([direct '\\' files{i}]);
        itembom(i).totalcost = sum(cell2mat({itembom(i).BOM.cost})*...
            cell2mat({itembom(i).BOM.quantity}));
        itembom(i).totaltime = sum(cell2mat({itembom(i).BOM.leadtime}));
    end
    bomdatabase(counter).itembom = itembom;
    bomdatabase(counter).product = params(1);
    clear files direct

    i2 = menu('Would you like to load another product?', 'Yes', 'No');
    if i2 == 2
        save('BOM_database.mat', 'bomdatabase')
        bom_optimizationgui
        close(handles.figure1)
        break
    end
    clear direct files itembom params

end
elseif bool == 0
    bom_optimizationgui
    close(handles.figure1)
end

function varargout = bom_optimizationgui(varargin)
% BOM_OPTIMIZATIONGUI M-file for bom_optimizationgui.fig
%     BOM_OPTIMIZATIONGUI, by itself, creates a new BOM_OPTIMIZATIONGUI
or raises the existing
%     singleton*.
%
%     H = BOM_OPTIMIZATIONGUI returns the handle to a new
BOM_OPTIMIZATIONGUI or the handle to
%     the existing singleton*.
%
```

```

%      BOM_OPTIMIZATIONGUI('CALLBACK',hObject,eventData,handles,...) calls
the local
%      function named CALLBACK in BOM_OPTIMIZATIONGUI.M with the given
input arguments.
%
%      BOM_OPTIMIZATIONGUI('Property','Value',...) creates a new
BOM_OPTIMIZATIONGUI or raises the
%      existing singleton*. Starting from the left, property value pairs
are
%      applied to the GUI before bom_optimizationgui_OpeningFcn gets
called. An
%      unrecognized property name or invalid value makes property
application
%      stop. All inputs are passed to bom_optimizationgui_OpeningFcn via
varargin.
%
%      *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only
one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help bom_optimizationgui

% Last Modified by GUIDE v2.5 29-Mar-2012 17:50:57

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',   gui_Singleton, ...
                  'gui_OpeningFcn', @bom_optimizationgui_OpeningFcn, ...
                  'gui_OutputFcn',  @bom_optimizationgui_OutputFcn, ...
                  'gui_LayoutFcn',  [] , ...
                  'gui_Callback',    []);
if nargin && ischar(varargin{1})

```

```

    gui_State.gui_Callback = str2func(varargin{1});
end

if nargin
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before bom_optimizationgui is made visible.
function bom_optimizationgui_OpeningFcn(hObject, eventdata, handles,
varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles     structure with handles and user data (see GUIDATA)
% varargin   command line arguments to bom_optimizationgui (see VARARGIN)

% Choose default command line output for bom_optimizationgui
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes bom_optimizationgui wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = bom_optimizationgui_OutputFcn(hObject, eventdata,
handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure

```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;

% --- Executes on selection change in popupmenu1.
function popupmenu1_Callback(hObject, eventdata, handles)
% hObject handle to popupmenu1 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns popupmenu1
contents as cell array
% contents{get(hObject,'Value')} returns selected item from
popupmenu1

% --- Executes during object creation, after setting all properties.
function popupmenu1_CreateFcn(hObject, eventdata, handles)
% hObject handle to popupmenu1 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
% See ISPC and COMPUTER.
load BOM_database.mat
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
set(hObject,'BackgroundColor','white');
end
handles.bomdatabase = bomdatabase;

```

```

set(hObject, 'String', [bomdatabase.product]);
guidata(hObject, handles)

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
selection = get(handles.popupmenu1, 'Value');
sumcost = sum([handles.bomdatabase(selection).itembom.totalcost]);
sumtime = sum([handles.bomdatabase(selection).itembom.totaltime]);
% for i = 1:length(handles.bomdatabase(selection).itembom)
%     handles.bomdatabase(selection).itembom(i).normcost = ...
%         handles.bomdatabase(selection).itembom(i).totalcost/sumcost;
%     handles.bomdatabase(selection).itembom(i).normtime = ...
%         handles.bomdatabase(selection).itembom(i).totaltime/sumtime;
%     handles.bomdatabase(selection).itembom(i).score = ...
%         handles.bomdatabase(selection).itembom(i).normcost +...
%         handles.bomdatabase(selection).itembom(i).normtime;
% end
for i = 1:length(handles.bomdatabase(selection).itembom)
    handles.bomdatabase(selection).itembom(i).normcost = ...
        handles.bomdatabase(selection).itembom(i).totalcost/sumcost;
    handles.bomdatabase(selection).itembom(i).normtime = ...
        handles.bomdatabase(selection).itembom(i).totaltime/sumtime;

    handles.bomdatabase(selection).itembom(i).score = ...
        handles.bomdatabase(selection).itembom(i).totalcost +...
        handles.bomdatabase(selection).itembom(i).normtime;
end
[~, bestbom] = min([handles.bomdatabase(selection).itembom.score]);

headercell = {'item' 'item code' 'unit' 'quantity' 'total cost'};

```



```

prompt = {'Enter amount of the product desired'};
dlg_title = 'Input Number';
num_lines = 1;
def = {''};
tempnum = inputdlg(prompt,dlg_title,num_lines,def);
tempnum = cell2mat(tempnum);
tempnum = str2double(tempnum);
if isempty(tempnum)
    errordlg('Please input a valid number')
    return
end

lengthprod = length(handles.bomdatabase(selection).itembom(bestbom).BOM);
printcell = cell(lengthprod,5);
for i = 1:lengthprod
    printcell{i,1}=
handles.bomdatabase(selection).itembom(bestbom).BOM(i).item;
printcell{i,2}=
handles.bomdatabase(selection).itembom(bestbom).BOM(i).itemcode;
printcell{i,3}=
handles.bomdatabase(selection).itembom(bestbom).BOM(i).unit;
printcell{i,4}=
handles.bomdatabase(selection).itembom(bestbom).BOM(i).quantity*tempnum;
printcell{i,5}=
handles.bomdatabase(selection).itembom(bestbom).BOM(i).quantity ...
    *handles.bomdatabase(selection).itembom(bestbom).BOM(i).cost*tempnum;
end

printcell = [headercell;printcell];
curdir = pwd;
xlswrite([handles.bomdatabase(selection).product{1}
'_optimized.xls'],printcell)
movefile([handles.bomdatabase(selection).product{1}
'_optimized.xls'],[curdir '\\' 'BOM_optimization_output'])

```

```

% --- Executes on button press in pushbutton2.
function pushbutton2_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
counter = length(handles.bomdatabase) + 1;
direct = uigetdir;

%Extract file names onto a cell variable
files = cellstr(ls(direct));
%Filter files to extract only text files
%Use temporary boolean variable
bool = find(cellfun(@isempty,strfind(files, '.xls'))== 0);
files = files(bool);
%Clear Boolean variable
clear bool
%Pre-declare dates variable outside of loop to
%Optimize code execution speed
itembom =
struct('itemname',cell(1,length(files)), 'version',cell(1,length(files)));
%Initiate loop to extract dates from file names
%Within the 'files' variable
for i = 1:length(files);
    %Split the filename string parameters
    params = strsplit(files{i}, '_');
    %store date parameter onto variable
    itembom(i).itemname = params(1);
    itembom(i).version = params(2);
end

for i = 1:length(files);
itembom(i).BOM = processBOM([direct '\\' files{i}]);
itembom(i).totalcost = sum(cell2mat({itembom(i).BOM.cost})).*...

```

```

        cell2mat({itembom(i).BOM.quantity}));
    itembom(i).totaltime = sum(cell2mat({itembom(i).BOM.leadtime}));
end
handles.bomdatabase(counter).itembom = itembom;
handles.bomdatabase(counter).product = params(1);
bomdatabase = handles.bomdatabase;
clear files direct
save('BOM_database.mat','bomdatabase')
close(handles.figure1)
bom_optimizationgui

function [BOM] = processBOM(filename)

[num, txt] = xlsread(filename);
txt(1,:) = [];

levels = num(:,2);
outputvar = zeros(1,length(levels));

for i = 1:length(levels)
    if i == length(levels)
        outputvar(i) = i;
        break
    end
    if levels(i+1) > levels(i)
        continue
    elseif levels(i+1) == levels(i)
        outputvar(i) = i;
    elseif levels(i) > levels(i+1)
        outputvar(i) = i;
    end
end
end

indexes = outputvar(outputvar ~= 0);

```

```

BOM =
struct('item',txt(indexes,1),'itemcode',vector2cell(num(indexes,1)),'unit'
,...
      txt(indexes,4), 'quantity',vector2cell(num(indexes,4)),'cost',...
      vector2cell(num(indexes,5)),'leadtime',vector2cell(num(indexes,6)));
end

function [BOM] = processBOM(filename)

[num, txt] = xlsread(filename);
txt(1,:) = [];

levels = num(:,2);
outputvar = zeros(1,length(levels));

for i = 1:length(levels)
    if i == length(levels)
        outputvar(i) = i;
        break
    end
    if levels(i+1) > levels(i)
        continue
    elseif levels(i+1) == levels(i)
        outputvar(i) = i;
    elseif levels(i) > levels(i+1)
        outputvar(i) = i;
    end
end

indexes = outputvar(outputvar ~= 0);

BOM =
struct('item',txt(indexes,1),'itemcode',vector2cell(num(indexes,1)),'unit'
,...
      txt(indexes,4), 'quantity',vector2cell(num(indexes,4)),'cost',...
      vector2cell(num(indexes,5)),'leadtime',vector2cell(num(indexes,6)));

```

end

```
function varargout = bom_initialgui2(varargin)
%BOM_INITIALGUI2 M-file for bom_initialgui2.fig
%     BOM_INITIALGUI2, by itself, creates a new BOM_INITIALGUI2 or raises
the existing
%     singleton*.
%
%     H = BOM_INITIALGUI2 returns the handle to a new BOM_INITIALGUI2 or
the handle to
%     the existing singleton*.
%
%     BOM_INITIALGUI2('Property','Value',...) creates a new
BOM_INITIALGUI2 using the
%     given property value pairs. Unrecognized properties are passed via
%     varargin to bom_initialgui2_OpeningFcn. This calling syntax
produces a
%     warning when there is an existing singleton*.
%
%     BOM_INITIALGUI2('CALLBACK') and
BOM_INITIALGUI2('CALLBACK',hObject,...) call the
%     local function named CALLBACK in BOM_INITIALGUI2.M with the given
input
%     arguments.
%
%     *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only
one
%     instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help bom_initialgui2

% Last Modified by GUIDE v2.5 04-Apr-2012 06:57:06
```

```

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',  gui_Singleton, ...
                  'gui_OpeningFcn', @bom_initialgui2_OpeningFcn, ...
                  'gui_OutputFcn',  @bom_initialgui2_OutputFcn, ...
                  'gui_LayoutFcn',  [], ...
                  'gui_Callback',    []);

if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargin
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before bom_initialgui2 is made visible.
function bom_initialgui2_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   unrecognized PropertyName/PropertyValue pairs from the
%            command line (see VARARGIN)

% Choose default command line output for bom_initialgui2
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

```

```

% UIWAIT makes bom_initialgui2 wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = bom_initialgui2_OutputFcn(hObject, eventdata,
handles)
% varargout    cell array for returning output args (see VARARGOUT);
% hObject     handle to figure
% eventdata   reserved - to be defined in a future version of MATLAB
% handles     structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject     handle to pushbutton1 (see GCBO)
% eventdata   reserved - to be defined in a future version of MATLAB
% handles     structure with handles and user data (see GUIDATA)

% eventdata   reserved - to be defined in a future version of MATLAB
% handles     structure with handles and user data (see GUIDATA)
mkdir('BOM_optimization_output2')
activedir = cellstr(ls);
bool = isempty(find(cellfun(@isempty,...
    strfind(activedir,'BOM_database1')) == 0));
if bool == 1
I = 1;
counter = 0;
while I == 1

counter = counter + 1;

```

```

direct = uigetdir;

%Extract file names onto a cell variable
files = cellstr(ls(direct));
%Filter files to extract only text files
%Use temporary boolean variable
bool = find(cellfun(@isempty, strfind(files, '.xls'))== 0);
files = files(bool);
%Clear Boolean variable
clear bool
%Pre-declare dates variable outside of loop to
%Optimize code execution speed
itembom =
struct('itemname',cell(1,length(files)), 'version',cell(1,length(files)));
%Initiate loop to extract dates from file names
%Within the 'files' variable
for i = 1:length(files);
    %Split the filename string parameters
    params = strsplit(files{i}, '_');
    %store date parameter onto variable
    itembom(i).itemname = params(1);
    itembom(i).version = params(2);
end

    for i = 1:length(files);
        itembom(i).BOM = processBOM2([direct '\ ' files{i}]);
    end
bomdatabase(counter).itembom = itembom;
bomdatabase(counter).product = params(1);
clear files direct

i2 = menu('Would you like to load another product?', 'Yes', 'No');
if i2 == 2
    save('BOM_database1.mat', 'bomdatabase')
    break

```



```

end
clear direct files itembom params

end
bool = 0;
end

    bool2 = isempty(find(cellfun(@isempty,...
        strfind(activatedir,'BOM_database2')) == 0));
if bool2 == 1
    matlistdir = uigetfilepaths;
    [matnum mattxt] = xlsread(matlistdir{1});
    mattxt(1,:) = [];
    save('BOM_database2.mat','matnum','mattxt','matlistdir')
end

if bool2 == 0 & bool == 0
    bom_optimizationgui2
    close(handles.figure1)
end

function varargout = bom_optimizationgui2(varargin)
% BOM_OPTIMIZATIONGUI2 M-file for bom_optimizationgui2.fig
%     BOM_OPTIMIZATIONGUI2, by itself, creates a new BOM_OPTIMIZATIONGUI2
or raises the existing
%     singleton*.
%
%     H = BOM_OPTIMIZATIONGUI2 returns the handle to a new
BOM_OPTIMIZATIONGUI2 or the handle to
%     the existing singleton*.
%
%     BOM_OPTIMIZATIONGUI2('CALLBACK',hObject,eventData,handles,...)
calls the local

```

```

%      function named CALLBACK in BOM_OPTIMIZATIONGUI2.M with the given
input arguments.
%
%      BOM_OPTIMIZATIONGUI2('Property','Value',...) creates a new
BOM_OPTIMIZATIONGUI2 or raises the
%      existing singleton*. Starting from the left, property value pairs
are
%      applied to the GUI before bom_optimizationgui2_OpeningFcn gets
called. An
%      unrecognized property name or invalid value makes property
application
%      stop. All inputs are passed to bom_optimizationgui2_OpeningFcn via
varargin.
%
%      *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only
one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help bom_optimizationgui2

% Last Modified by GUIDE v2.5 04-Apr-2012 08:08:26

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                  'gui_Singleton',  gui_Singleton, ...
                  'gui_OpeningFcn', @bom_optimizationgui2_OpeningFcn, ...
                  'gui_OutputFcn',  @bom_optimizationgui2_OutputFcn, ...
                  'gui_LayoutFcn',  [] , ...
                  'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

```

```

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT

% --- Executes just before bom_optimizationgui2 is made visible.
function bom_optimizationgui2_OpeningFcn(hObject, eventdata, handles,
varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to bom_optimizationgui2 (see VARARGIN)

% Choose default command line output for bom_optimizationgui2
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes bom_optimizationgui2 wait for user response (see UIRESUME)
% uiwait(handles.figure1);

% --- Outputs from this function are returned to the command line.
function varargout = bom_optimizationgui2_OutputFcn(hObject, eventdata,
handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

```

```

% Get default command line output from handles structure
varargout{1} = handles.output;

% --- Executes on selection change in popupmenu1.
function popupmenu1_Callback(hObject, eventdata, handles)
% hObject    handle to popupmenu1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: contents = cellstr(get(hObject,'String')) returns popupmenu1
contents as cell array
%         contents{get(hObject,'Value')} returns selected item from
popupmenu1

% --- Executes during object creation, after setting all properties.
function popupmenu1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to popupmenu1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: popupmenu controls usually have a white background on Windows.
%         See ISPC and COMPUTER.
load BOM_database1.mat
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
handles.bomdatabase = bomdatabase;

```

```

set(hObject, 'String',[bomdatabase.product]);

load BOM_database2.mat

handles.mattxt = mattxt;
handles.matnum = matnum;

guidata(hObject,handles)

% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
selection = get(handles.popupmenu1, 'Value');

% for i = 1:length(handles.bomdatabase(selection).itembom)
%     handles.bomdatabase(selection).itembom(i).normcost = ...
%         handles.bomdatabase(selection).itembom(i).totalcost/sumcost;
%     handles.bomdatabase(selection).itembom(i).normtime = ...
%         handles.bomdatabase(selection).itembom(i).totaltime/sumtime;
%     handles.bomdatabase(selection).itembom(i).score = ...
%         handles.bomdatabase(selection).itembom(i).normcost +...
%         handles.bomdatabase(selection).itembom(i).normtime;
% end
bestmats = zeros(length(handles.bomdatabase(selection).itembom.BOM),1);
for i = 1:length(handles.bomdatabase(selection).itembom.BOM)
    indexes1 =
find(cellfun(@isempty, strfind(lower(handles.mattxt(:,1)), lower(handles.bom
database(selection).itembom.BOM(i).item)))==0);
    costvect = handles.matnum(indexes1,4);
    timevect = handles.matnum(indexes1,5);
    costvect = costvect/sum(costvect);
    timevect = timevect/sum(timevect);

```

```

score = costvect+timevect;

[~, bestmat] = min(score);
if length(bestmat) > 1
bestmats(i) = indexes1(bestmat(1));
else
    bestmats(i) = indexes1(bestmat);
end
end

headercell = {'item' 'item code' 'unit' 'quantity' 'total cost'};

prompt = {'Enter amount of the product desired'};
dlg_title = 'Input Number';
num_lines = 1;
def = {''};
tempnum = inputdlg(prompt,dlg_title,num_lines,def);
tempnum = cell2mat(tempnum);
tempnum = str2double(tempnum);
if isempty(tempnum)
    errordlg('Please input a valid number')
    return
end

lengthprod = length(handles.bomdatabase(selection).itembom.BOM);
printcell = cell(lengthprod,5);
for i = 1:lengthprod
    printcell(i,1)= handles.mattxt(bestmats(i),1);
printcell{i,2}= handles.matnum(bestmats(i),1);
printcell(i,3)= handles.mattxt(bestmats(i),3);
printcell{i,4}=
handles.bomdatabase(selection).itembom.BOM(i).quantity*tempnum;

```

```

printcell{i,5}=
handles.bomdatabase(selection).itembom.BOM(i).quantity*tempnum*handles.mat
num(bestmats(i),4);
end

printcell = [headercell;printcell];
curdir = pwd;
xlswrite([handles.bomdatabase(selection).product{1}
'_optimized.xls'],printcell)
movefile([handles.bomdatabase(selection).product{1}
'_optimized.xls'],[curdir '\\' 'BOM_optimization_output2'])

% --- Executes on button press in pushbutton2.
function pushbutton2_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
counter = length(handles.bomdatabase) + 1;
direct = uigetdir;

%Extract file names onto a cell variable
files = cellstr(ls(direct));
%Filter files to extract only text files
%Use temporary boolean variable
bool = find(cellfun(@isempty,strfind(files, '.xls'))== 0);
files = files(bool);
%Clear Boolean variable
clear bool
%Pre-declare dates variable outside of loop to
%Optimize code execution speed
itembom =
struct('itemname',cell(1,length(files)), 'version',cell(1,length(files)));
%Initiate loop to extract dates from file names
%Within the 'files' variable

```

```

for i = 1:length(files);
    %Split the filename string parameters
    params = strsplit(files{i},'_');
    %store date parameter onto variable
    itembom(i).itemname = params(1);
    itembom(i).version = params(2);
end

for i = 1:length(files);
itembom(i).BOM = processBOM([direct '\ ' files{i}]);
itembom(i).totalcost = sum(cell2mat({itembom(i).BOM.cost})*...
    cell2mat({itembom(i).BOM.quantity}));
    itembom(i).totaltime = sum(cell2mat({itembom(i).BOM.leadtime}));
end
handles.bomdatabase(counter).itembom = itembom;
handles.bomdatabase(counter).product = params(1);
bomdatabase = handles.bomdatabase;
clear files direct
save('BOM_database.mat','bomdatabase')
close(handles.figure1)
bom_optimizationgui2

```


Appendix J

Sample of BOM and General Suppliers Information

Item	Code	Unit	Quantity	Cost
FT 12" XH 1333 GR6 SMLS DR	1154788	inch	170	
FT 12" XH 1333 GR6 SMLS SR	1154328	inch	270	
FT 12" XH 1333 GR6 SMLS SR – Hydro Testing	1154242	inch	20	
FT 8" XH A333 GR6 SMLS	1158486	inch	20	
FT. 15" XH A106B SMLS DR	1166788	inch	80	
FLANGE 12" PN100 RFWN XH A350LF2 CL1	1165879	inch	10	
FLANGE 8" PN100 RFWN STD A350LF2 CL1	1165910	inch	1	
FLANGE 4" PN100 RFWN STD A350LF2 CL1	1165941	inch	3	
FLANGE 2" PN100 RFWN XH A350LF2 CL1	1165972	inch	4	
FLANGE 4" PN100 RF BLIND A350LF2 CL1	1166003	inch	1	
FLANGE 2" PN100 RF BLIND A350LF2 CL1	1166034	inch	2	
ELBOW 90 LR 12" XH A420WPL6	1768688	inch	13	
ELBOW 90 LR 8" STD A420WPL6	1768755	inch	2	
ELBOW 90 LR 2" XH A420WPL6	1768822	inch	1	
ELBOW 90 1.5" 3M THREADED A105	1768889	inch	11	
CONIC REDUCER 12" X 8" XH x STD A420WPL6	1768956	inch	3	
NIPPLE PBE 1.5" XH 4" LONG A106B	1769023	inch	9	
NIPPLE TBE 1.5" XH 4" LONG A106B	1769090	inch	24	
SWAGE CONC THRD 1.5" x 0.5" XH A234WPB	1157777	inch	6	
UNION THRD 1.5" 3M A105	1323255	inch	8	
BULL PLUG HEX SOLID BODY 1.5" 6M A234WPB	1766978	inch	8	
BULL PLUG HEX SOLID BODY 0.5" 6M A234WPB	1766646	inch	7	
TEE STRAIGHT THRD	1687878	inch	10	
SOCKOLET 30" x 1.5" 3M A105	1168688	inch	4	
SOCKOLET 12" x 1.5" 3M A105	1165678	inch	4	
SOCKOLET 8" x 1.5" 3M A105	1164564	inch	1	
SOCKOLET 12"-8" x 1.5" 3M A105	1168877	inch	2	
WELDOLET 36" x 2" XH A350LF2	1798998	inch	2	
BUSHING THRD HEX BODY 1.5" x 0.5" 6M A105	1454555	inch	5	

Supplier 1

- Local to project site, no delivery fees
- Supplier has knowledge of Aecon's policies and procedures for delivery
- Supplier on Aecon Industrial's Approved Supplier's List (ASL)
- Proven reliable over years of supply to Aecon
- Quick order turnaround
- Documentation is always correct and accompanies the shipment (MTR's, CofC's, CRN's)
- Problems with orders are fixed immediately by our inside sales contact
- Invoicing issues are fixed immediately, and credits are issued right away
- Early Payment Discount if payment made within terms
- Preferred Supplier of Aecon Group Inc. allowing us to take valuable rebates on sales at the end of the year

Supplier 2

- Not local to project site, additional delivery fees will apply
- Supplier is not on Aecon's Approved Supplier's List (ASL)
 - Supplier will have to fill out Evaluation form and submit to Quality Control for review and possibly audit
 - Quality Control will have to evaluate and approve or deny (process could be quick or lengthy depending on supplier's certifications, qualifications, and internal quality programs)
- Unknown order turnaround time
- Documentation will have to be supplied with the order, but no guarantee that it will all be with the order and be correct as per heat/lot numbers (MTR's, CofC's, CRN's)
- Unsure if problems with order will be fixed as quickly as Supplier 1
- Unsure if invoicing issues will be fixed as quickly as Supplier 1
- No Early Payment Discounts to take advantage of
- Not a Preferred Supplier of Aecon Group Inc., so no yearend rebates

Supplier 3

- Distributor, local to project site, no delivery fees
- Supplier has great knowledge of Aecon's policies and procedures for delivery
- Supplier on Aecon Industrial's Approved Supplier's List (ASL)
- Proven reliable over years of supply to Aecon
- Quick order turnaround
- Documentation is always correct and accompanies the shipment (Packing Slips, MSDS, CofC's)
- Problems with orders are fixed immediately by our inside sales contact
- Invoicing issues are fixed immediately, and credits are issued right away
- Early Payment Discount if payment made within terms
- Preferred Supplier of Aecon Group Inc. allowing us to take valuable rebates on sales at the end of the year

Supplier 4

- Distributor, local to project site, no delivery fees
- Supplier has great knowledge of Aecon's policies and procedures for delivery
- Supplier on Aecon Industrial's Approved Supplier's List (ASL)
- Proven reliable over years of supply to Aecon
- Quick order turnaround
- Documentation is always correct and accompanies the shipment (Packing Slips, MSDS, CofC's)
- No Early Payment Discounts to take advantage of
- Not a Preferred Supplier of Aecon Group Inc., so no yearend rebates

Supplier 5

- Distributor, local to project site, no delivery fees
- Supplier has ok knowledge of Aecon's policies and procedures for delivery.
- Supplier on Aecon Industrial's Approved Supplier's List (ASL).
- Documentation not always correct and does not always accompany the shipment (Packing Slips, MSDS, CofC's)
- Problems with orders are not always fixed immediately
- Often unreliable and inconsistent performance (late deliveries, poor internal communication, weak links in supply chain)
- Most material comes from the US via Distribution Center. Min 2-3 days to ship most products.
- Trucks could be too full to fit your order, and no communication from DC to Distributor to let them know. Order is then late.
- No Early Payment Discounts to take advantage of.
- Preferred Supplier of Aecon Group Inc. allowing us to take valuable rebates on sales at the end of the year
- Recently expanded product scope from primarily fasteners, to a wide range of industrial tools and consumables.

Factors Affecting Weighting

- Supplier ... can deliver sooner than Supplier...due to physical location and supply capabilities
- This project has a tight schedule, and material is on the critical path (ex. Shutdown)
- If problems arise with this order, the schedule will be impacted and a significant number of trades people will be standing idle
- The Client is OPG, a high-profile partner for Aecon Industrial and we will deliver on all promises we make to them no matter what
- Early Payment with Supplier ... will earn Aecon Industrial ...% cash rebate on this order alone. This rebate hits our bottom line directly.

Weighting

Price	20%
Lead Time	30%
Supplier Performance	40%
Preferred Supplier/Early Payment	<u>10%</u>
Total	100%

Appendix K

Glossary of Terms

A.1 Value Unit: the value unit divides work by types, stages, and places of fabrication. A value unit is usually associated with the following:

1. A list of potential contractors
2. The location and method of the work (e.g. on-site, off-site, fab-shop, etc.)
3. Drawings
4. A detailed description of the scope of the work
5. A detailed bill of materials (BOM) that specifies all quantities that make up the scope of the work
6. Human resources information
7. A list of fixtures, fittings and equipment
8. A process schedule that details the commencement and completion dates and also includes detailed schedules and spreadsheets that show the tracking, monitoring, and closing out of all activities from the start to the completion of each process
9. An inventory policy
10. A plan of all movement on site
11. Technical requirements, references, and information
12. Quality assurance (QA) for auditing all materials and modules

A.2 Value Package: A set of value packages is an optimized, aggregation of value units.

A.3 Value: Value is how much a desired value package is worth relative to other feasible value packages. The value usually is presented as less cost but several tangible (e.g. location and method of the work) and intangible (e.g. familiarity with local working culture) criterion must be consider to evaluating the value of the work package.

A.4 Interface Management: the management of communication, coordination and responsibility across a common boundary between two value unit providers, value units, or value packages which are interdependent. It effects on all relations between stakeholders of the project.

A.5 Value unit provider (VUP): can be considered to refer to contractor, supplier, and vendor.

A.6 Inbound Transmittal: One method to initiate the workflow is when Documents are received from an external party via an inbound transmittal. The inbound transmittal process takes all validated Documents and loads them to the appropriate document archive, along with metadata.

A.7 Comment Sheet Consolidation: All reviewer Comment Sheets are consolidated into one Comment Sheet for the work package. Once completed, the approver is immediately sent his approval assignment.

A.8 Initiated Workflow: An authorized user may also initiate the workflow. Using the Document Cart, the user selects the documents to send on the workflow.

A.5 Resource Assignment: All validated documents are grouped into logical value packages that will be sent to a common group of reviewers and approvers. The resource assignment rules are maintained in the responsibility matrix for the project. The responsibility matrix will define Work Groups who will be the reviewer and approver to be assigned based on selected document attributes such as area, issue purpose, discipline, and document type.