LOGISTICS IN COMPUTER INTEGRATED CONSTRUCTION FRAMEWORK

by

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ABSTRACT

Information technology implementation in construction witnessed major progress in recent years. Hardware and software technology improvements allowed computer use in most of the companies. However there is still much to go to achieve effective and integrated information systems and gain real benefits. Similarly logistics concept, evolved from manufacturing materials management and distribution gains much more importance because of globalization of the world, reduced time to market and customer driven approach. Effective integration of these vital concepts will undoubtedly reveal highly efficient construction.

This study particularly investigates construction logistics from information technology point of view considering the current and future trends. Following the recent literature survey to present computer integrated construction idea, an integrated logistics concept in construction is explained. Then a reference data model of construction logistics for construction enterprises is proposed. This model is partially implemented using a relational database management system and object oriented development environment. A case study in a process plant construction is developed to demonstrate the concepts developed throughout the study.

ÖZET

İnşaat dünyası geçtiğimiz yıllarda bilişim teknolojileri uygulamalarında büyük ilerlemelere tanık oldu. Donanım ve yazılım teknolojileri gelişmeleri firmaların büyük bir kısmının bilgisayar kullanmasına imkan tanıdı. Ancak etkin ve entegre bir bilişim sistemini elde etmek için hala alınması gereken yollar var. Aynı şekilde üretim malzeme yönetimi ve dağıtımından türeyen lojistik kavramı dünyanın globalleşmesi, kısalan pazar süresi, ve müşteri yönelimli yaklaşımlar dolayısıyla daha çok önem kazanıyor. Bu önemli kavramların etkin bütünleşimi şüphesiz daha etkin inşaatları ortaya çıkaracaktır.

Bu çalışma inşaat lojistiğini, günümüz ve gelecek eğilimleri göz önünde bulundurarak, özellikle enformasyon teknolojisi bakış açısından incelemektedir. Bilgisayarla bütünleşik inşaat literatür araştırmasını takiben, entegre lojistik kavramı açıklanmıştır. Ardından inşaat firmalarında inşaat lojistiği için referans veri modeli öne sürülmüştür. Bu model bir ilişkisel veritabanı yönetim sistemi ve nesne yönelimli bir geliştirme ortamı kullanılarak kısmen uygulanmıştır. Bu çalışma boyunca oluşturulan kavramları uygulamak amacıyla bir proses fabrikası inşaatı için bir vaka çalışması açıklanmıştır.

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1. INTRODUCTION

Projects in architecture/engineering/construction (A/E/C) have significant information handling requirements. They are complex, having many physical components like structural elements, equipments and furnishings, also nonphysical components such as schedules, construction methods, and code requirements. A construction project involves a number of phases from feasibility study through programming, design and construction planning to construction and on to operation and maintenance and finally to the eventual disposal or refurbishment of the facility. It has high information intensity both in the value-chain system and often also in the final products. Moreover, the constructed facility often requires much information for its operation and maintenance [1].

Many professionals contribute to each phase from different organizations and departments. A contractor has to deal with several subcontractors and vendors on a project, and typically with a different owner on every job. Information is exchanged back and forth at all times. Information created at each point needs to be represented and stored effectively and non-redundantly. Information about previous projects can be very useful in future projects. Also each participant should be capable of responding quickly to changes in the project or the environment.

These factors call for an effective information handling requirement in construction. Thus, A/E/C research community has recognized enormous potential benefits that information technology (IT) offers and, thus, is pushing for greater IT use in the industry. IT becomes an enabling technology that provides the opportunity to formalize and rationalize the methods of executing projects.

The islands of automation in construction is caused by successful automation in certain functions and not achieving the integration between them. Computer Integrated Construction (CIC) concept, which has a target to acquire integrated information systems in construction, is the promising vision for handling intensive information requirements for construction.

In this study logistics is referred to as a total approach to the planning, implementing, and controlling the efficient, cost effective flow and storage of all activities from physically acquiring, moving and storing to the point of use or consumption of materials and related resources. Logistics and supply chain management has evolved from manufacturing companies and has many applicable ideas for construction enterprises. Today, business logistics has gained respectability and importance for companies in almost all industries and market. Because logistics spans all key corporate functions, logistics by nature plays a strategic role in the balance of a company. Making use of CIC for construction logistics will surely reveal efficient construction logistics implementation.

A process model of logistics-related functions in construction enterprises is proposed in this study. Architecture of Integrated Information Systems (ARIS) methodology is used as the process modeling tool. The functions are analyzed in a generic framework for construction companies to allow for achieving computer integrated logistics. Modeling diagrams for the data, functions and processes in the integrated system are presented. A database management system for various applications, an integrated development environment and a network system are the basic elements to be analyzed. Following the design, the data model is implemented on a relational database management system. The user interface and some functions are implemented in an object oriented development environment. This study provides a basis for further research in all of the logistics related functions. Implementation of all of the functions are extensible with complex applications and mathematical models. A brief case study is implemented to illustrate the use of the system.

This research will provide an extensive literature survey in Chapter 2. Firstly, the necessity for effective information implementation in construction is justified and CIC concept is explained. Similarly, logistics and supply chain management concept is explained and research and applications to construction is summarized. The problem statement is given in Chapter 3, and Chapter 4 includes an explanation of the ARIS methodology, the enterprise process modeling tool used throughout the definitions of the functions for construction logistics. Chapter 5 realizes the process analysis of logistic functions in construction. The core areas of a construction enterprise related to logistics are analyzed and an information framework for each of them are defined. The essentials of logistics, as well as the recent improvements in information technology are integrated in this framework. Chapter 6 describes the implementation of the framework and provides the implementation of the ideas in a hypothetical case study, while Chapter 7 provides the concluding remarks.

2. LITERATURE SURVEY

2.1 Construction Information Systems

Improvements in hardware technology are resulting in cheaper and more powerful desktop machines, and the computing resources in an organization are spreading thoroughly. At the same time, end users acquire more responsibility and autonomy, becoming independent of computer representatives. Computer industry grasped the client/server architecture, following object oriented trend, taking all the advantage distributed systems and Internet provide. A/E/C industry is a late follower of the computer industry, but these changes will inevitably have an impact on construction industry [2].

From the project manager's point of view, data from past projects stored in a historical database and current project data must be readily available. Data are essential and valuable resource for construction project planning, control, reporting and decision making tasks [3]. Effective information management which is an integral part of a successful project improves quality, alleviates technical personnel of clerical duties, automates work, standardizes procedures, and maintains flexibility rather than restricting.

Projects are evaluated mostly on their profitability and timeliness. Thus, few project managers have tried to implement state-of-the-art computer system which is a potential negative effect on profitability and productivity, at least for that particular project. Many people have been unwilling to use computers and A/E/C industry has slowly increased the use of IT. However IT in A/E/C industry has to be treated as an investment that can provide beneficial returns, rather than a cost.

Successful implementation of IT has managerial and organizational aspects also. IT in business has evolved from bulk data processing to strategic information systems in the last 30 years. Strategic information systems are not only critical to the normal functioning of a business, but can also alter the nature of competition by changing the industry structure and its competitive forces. Breuer *et al.* reported that the A/E/C industry has generally not been able to use information systems in a strategic way [1]. However, a firm may not achieve competitive advantage using IT without changing procedures and organizations.

IT has historically been relegated to support function in most of the A/E/C firms, where critical decisions have been left to IT specialists. Because information systems will become increasingly influential on the success or failure of operations, firms must regard them as an integral part of the business. Thus senior management involvement in IT decisions is important, as only senior management can resolve power and authority conflicts originated by the introduction of new a form of IT.

Extensibility, a model's ability to change over time, is also important in a large scale information system. In an A/E/C project, the amount of information grows steadily as the project progresses. There may be many views on a single project. Architects are interested in the spatial layout, engineers focus on the structural systems, and contractors deal with the project's construction processes.

2.2 Computer Integrated Construction (CIC)

A/E/C information has been traditionally exchanged through drawings and reports. However, computers are increasingly becoming the primary medium for storing and processing project information. There are communication protocols that exist to transfer low-level data but are often ineffective in bridging the gap between the islands of information, since each application represents and processes project information in different ways. **Figure 2.1** illustrates the current status in construction information exchange [4].

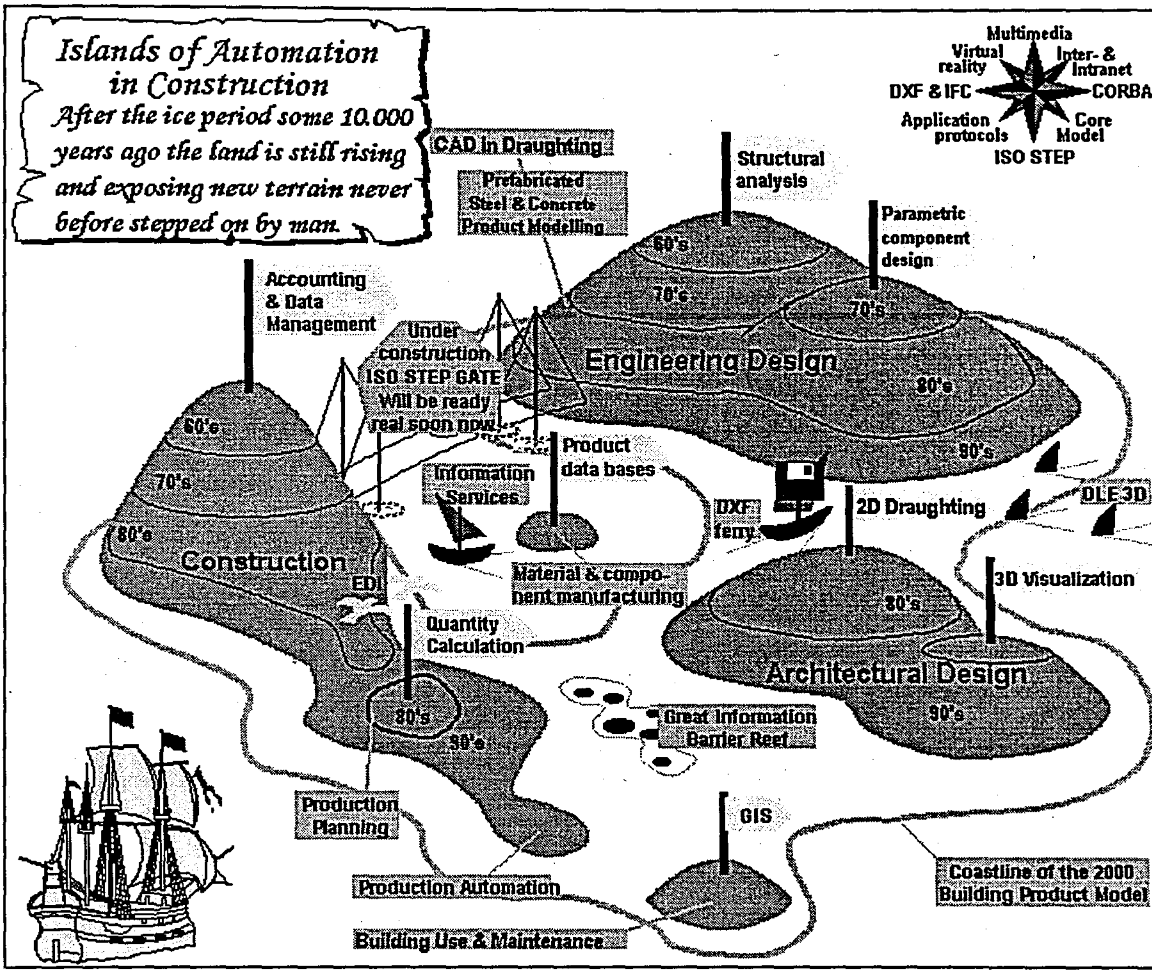


FIGURE 2.1. Islands of Automation in Construction [4]

Downward cost pressures, coupled with ever more specialized building trades and the increasing technical complexity of all projects create a demand for integration of construction information. The intensity of competition has been fueled by factors such as the fragmentation of the industry, the globalization of the market, and the enhanced bargaining power of customers, who are becoming more difficult to please [3]. Good progress has been made in the automation of some design and construction activities. However the integration of these activities is severely lacking in the construction industry. Development of new software applications, improvements in network technology, automation and robotics in construction, development of languages and standards for the information exchange create new opportunities for integration. Indeed construction has yet to achieve the levels of design process integration found in automotive and aerospace industries. These factors led to the development of computer integrated construction concept.

Teicholz, Fischer [5] defined computer integrated construction (CIC) as "a business process that links the project participants in a facility project into a collaborative team through all phases of a project". Each team member should be able to share data with other team members on a frequent (perhaps real time) basis. The use of technology to facilitate and share data and knowledge is an integral part of CIC. CIC provides a link between existing and emerging technologies and people in order to optimize various functions during a facility delivery process. Their view of CIC is shown in **Figure 2.2.** In this view, all the project functions, processes and models are defined in conjunction with the product model of 3D CAD objects. Interoperability, which is the capability to share AEC information distributed among heterogeneous models and participants, is the key word in CIC. Specific benefits from CIC can be stated as a reduction in time requirements, and errors for data input and output, accelerated communication among participants, and improved completeness of information received by each team member. Primary goals of CIC are rapid top-quality design, fast and cost effective construction, and effective facility management.

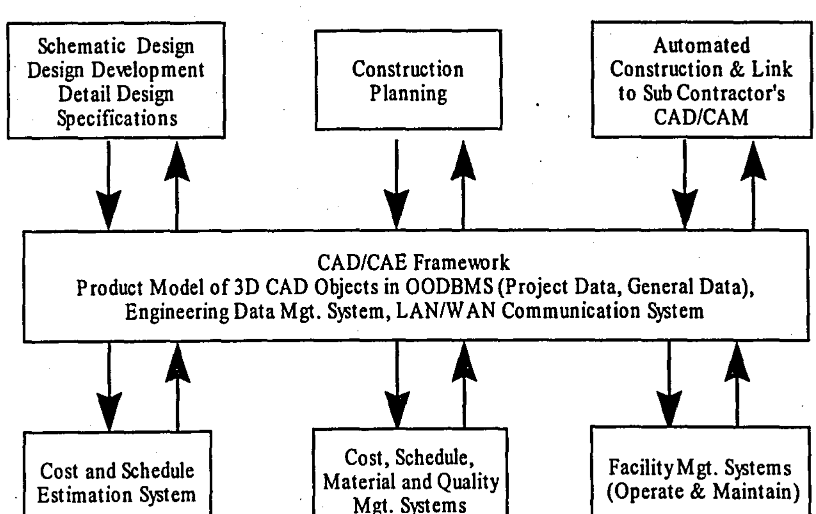


FIGURE 2.2. Computer Integrated Construction Model [4]

There are other ongoing A/E/C integration efforts in the world. Finnish construction industry has gone through an industry and research cooperation to achieve CIC in an project named RATAS [6]. Similarly there are continuing efforts in Europe to integrate construction project information with varying degree of success. ATLAS [7] (for large scale engineering), COMBINE [8] (for HVAC and building design), ICON and COMMIT [9-10] are examples of these efforts. The ICON project (Information/Integration for CONstruction) investigated the feasibility of establishing a framework for integrated information systems in the construction industry and to propose a methodology for the development of integrated databases in general, whereas COMMIT project is the successor of ICON covering ongoing STEP building core model, which will be mentioned later in the chapter.

Manufacturing industry have gone through a successful, extensive implementation of computer tools to integrate the manufacturing process. This had a positive impact on productivity and time to market. However there is an important difference between construction and manufacturing. In manufacturing, the designers, engineers, and the fabrication specialists all work for, or are captive subcontractors of, the same firm. The trend towards JIT manufacturing further results in tighter integration between the manufacturer and supplier or subcontractor. By contrast, in the construction industry, architectural, engineering, fabrication, construction and facilities management activities are often distinct economic units with different objectives and long-term business policies [11].

Fisher *et al.* reported that integration may occur in three levels. Integration among various applications used on a single platform such as scheduling, resource management, document management is called *application level* integration. Sharing of project information between project participants is *system level* integration. More generally, industry-wide electronic communication of information is *industry level* integration [4].

3D CAD generally plays an important role in integration. 3D CAD captures the various components in a project, the relationships between these components, and the behavior of these components with project data. Gibson *et al.* [12] named this structure as integrated database system(IDS). The IDS concept effectively combines graphical CAD data and traditional non-graphical data that are utilized for estimating, scheduling, materials management, cost accounting, and other project-management functions but lacks semantic relationships and behaviors of components.

The highest degree of computer integrated construction has been achieved in the field of process plant construction. This is attainable to the high cost of a single project, and the cost associated with the information system was justified by the productivity of integrated system even at the early days of information systems. The integrated database for process plant design/construction/maintenance is summarized in **Figure 2.3** [5, 13]. The design begins with process flow diagrams that define flows, temperatures, fluids involved in the process. This definition comes from the owner or an engineering firm. Then the process flow diagrams are translated into piping and instrumentation diagrams (P&ID) that shows the necessary equipment, piping, and valves needed to accomplish this process. This is the most critical step in the design process, since all the following work is based on this schematic model of the plant. The P&ID and the 3D model can be worked out concurrently using a state of the art plant design software (Cadcentre PDMS may be one of the examples [14]). After the completion and the approval of the P&ID, the detail plant design starts. In addition, the civil engineering analysis and design can be started and overlapped with a portion of the detail plant design.

Detailed design includes selection of specific equipment, routing of pipe, selection of valves, and fittings, and the design of the control systems required for the plant. These processes can be automated to a degree. The 3D CAD model from detailed design can be linked to the P&ID model which permits automated design development and checking. It also allows rapid changes to the design which affects both representations. This results in more accurate and higher quality design that is produced in shorter time in fewer man-hours.

Before 3D CAD models were available, very detailed plans and elevation drawings were required [13]. The redundancies between the data sources necessitated manual checkers to find and correct data inconsistencies. 3D CAD completely eliminate separate plan and elevation drafting process. 3D CAD systems can produce any view of a computer model (single and/or double line plan, elevation, or isometric view) as well as detailed isometrics, spool drawings or bill of quantities.

Other downstream processes that can benefit from the use of 3D plant models include:

(A) EDI transactions for ordering materials (Bill of Quantities directly from 3D model)
(B) NC programs used for pipe handling, bending, end preparation, or welding
(C) real-time 3D model simulation on high performance graphics workstations for design review, construction sequencing, or training
(D) identification and inspection points in plant
(E) disaster scenario modeling (vapor clouds, fire, explosions, or spills) which requires spatial information unavailable in process flow diagrams or P&ID's
(F) construction planning and simulation applications, such as computer aided planning for heavy lifts by Hornaday [15]
(G) 3D plant model is used as the seed for procurement, control and manufacturing systems

As the detail design progresses in parallel, but ahead of construction, the linkage between design and construction applications allows rapid and accurate transmission of changes. In addition, the 3D model provides information for plant modification and operation. Thus the client has most to gain from improved integration and automation of the design and the construction process.

Successful CIC requires a new emphasis on the project information itself [4]. Project model is used to refer to the collection of information that represents, describes, or abstracts A/E/C projects. In traditional stand-alone applications, the data model is a function of that application alone, it is not influenced by nor does it influence anything outside of the application. The goal must be shared project models, which exist independently of any one particular application, standing as a conceptual layer beneath the applications.

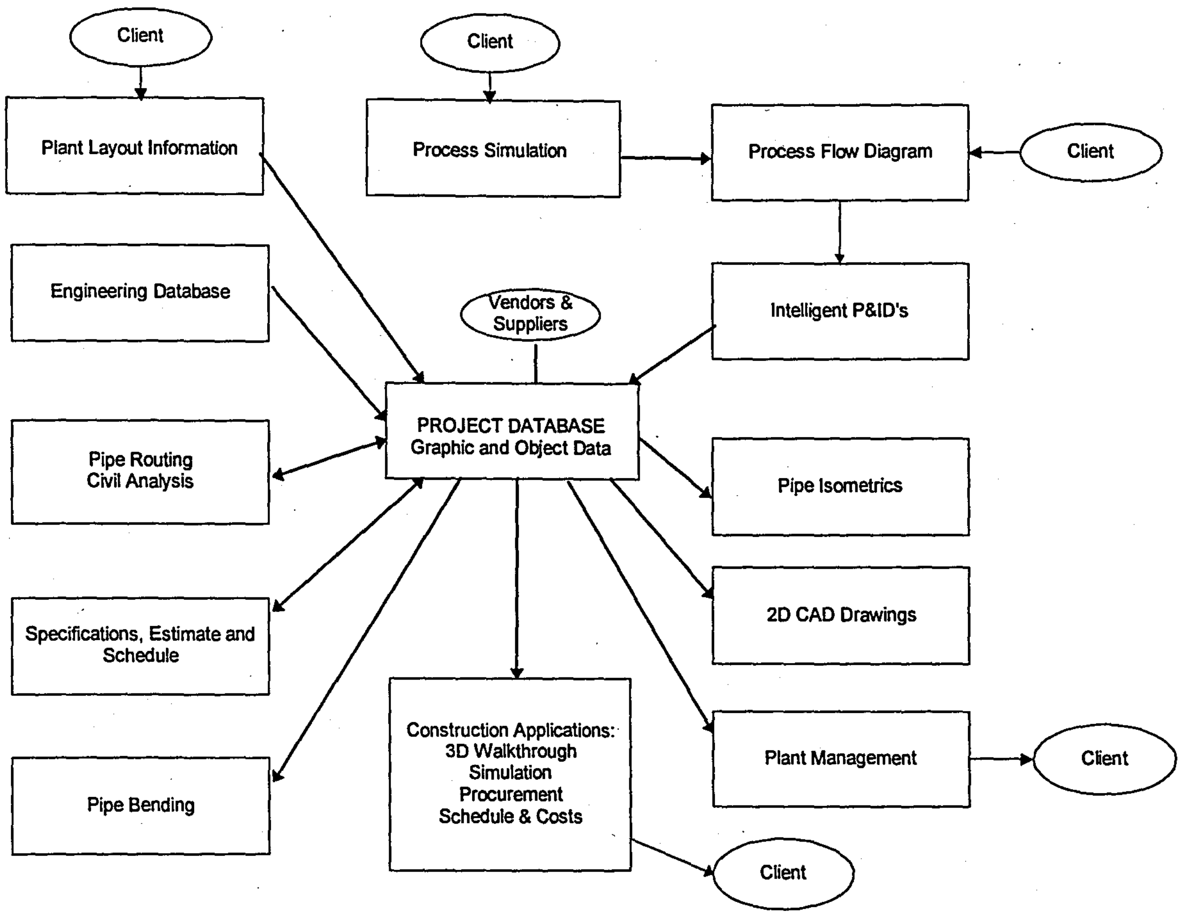


FIGURE 2.3. Process Plant Integrated Database

A single generic project model for construction is away from reality, inherent to the scattered and multidisciplinary nature of building industry [10]. A/E/C has fuzzy boundaries and covers a wide range of technologies, a large variety of heterogeneous software tools are being used, and the scope of exchanged data varies between nations, companies, projects, application systems and current view of the user.

There are several project models developed to represent construction product and process information. The largest and most significant of them is ISO Standard 10303 or STEP. STEP is an international effort to provide a computer-interpretable unambiguous method for exchanging product data to and from any system [16]. This work includes the development of standards to specify generic resources and methods for representing libraries of standardized product descriptions. The development of resource models, and the development of methods will facilitate product information description and exchange.

A product data description applies throughout the life cycle of a product and is independent of any particular hardware or software platform.

STEP does not attempt to produce a single standard model that applies across disciplines. Rather, the STEP approach is to produce standard product models for use within specific areas of application, called *Application Protocols (AP's)*, and to strive to harmonize and coordinate these models across application areas to the greatest extent possible. The role of the AP is documented in Application Activity Model. The AAM describes the processes for an industrial application. It is normally created in IDEF0. Application Reference Model (ARM) defines an object model that defines the data, relations and constraints of semantic elements. It is normally created in NIAM or IDEF1x. Application Interpreted model is an EXPRESS model developed from the ARM and the STEP integrated resources. There is an explicit mapping between every ARM object and its AIM counterpart.

A final current work item of the STEP building construction group is *Part 106, the Building Construction Core Model (BCCM)* project [17]. The BCCM is an Integrated Application Resource i.e. a model intended to serve as a unifying reference for building construction AP's. More specifically, three possible roles have been identified for the BCCM:

(A) *Kernel:* The core model should provide a basic model of the central building construction concepts that are common to all areas of the industry. Individual AP's within the industry, then, can adopt this kernel model and develop various areas in greater detail to suit the needs of the particular application area. This ensures a commonality of approaches among construction AP's.

(B) *Common references:* Beyond a central kernel, there are many more detailed areas that are common to two or more applications within building construction and it is desirable to treat these areas in a consistent way. One role of the core model, then, is to act as a library of common reference models, or model constructs that apply to multiple construction areas.

(C) *Common data:* AP's are developed to allow information exchange among programs *within* an application area (e.g., within the structural design area). However, information also needs to be exchanged *between* application areas (e.g., to use design information for estimating). Information exchanged between application areas generally needs to be much less detailed than information exchanged within an application area. Another possible role of a core model, then, is to support the exchange of information between application areas, a capability not presently facilitated within the STEP framework

Figure 2.4 shows some basic objects of the BCCM. EXPRESS-G graphical notation, which is used extensively in STEP ARM definitions, is employed to illustrate the objects. Entities are represented as labeled boxes, specialization relationships are represented as heavy lines, and other association relationships are represented as labeled lines. BC_Project object is an abstract super-type of most project information. Process objects represent processes or actual design and construction effort on the project. Processes are performed by actors, they apply resources and process input products, they have preceding and succeeding processes, and they result in other project objects. Logistics is a subtype of process. Product objects are systems and components of the constructed facility itself. Resource objects represent the resources used in carrying out processes. Control objects are items that control, influence, or constrain other project objects, such as contracts, budgets, design standards, etc.

The latest and promising attempt comes from A/E/C industry with Industry Foundation Classes. Established in 1995, the Industry Alliance for Interoperability(IAI) develops the Industry Foundation Classes (IFC) [18]. The IFC are libraries of object classes that are commonly useful to an industry. It tries to provide "a mechanism for object sharing, which equals interoperability across the boundaries of software applications". The IAI has started with an original group of twelve companies involved in the A/E/C and Facilities Management including Autodesk and Bentley Systems. Currently the IAI has over 300 member companies in seven international chapters, and is growing rapidly. IAI has agreed with STEP committee to harmonize their technical approach and to collaborate on common tasks.

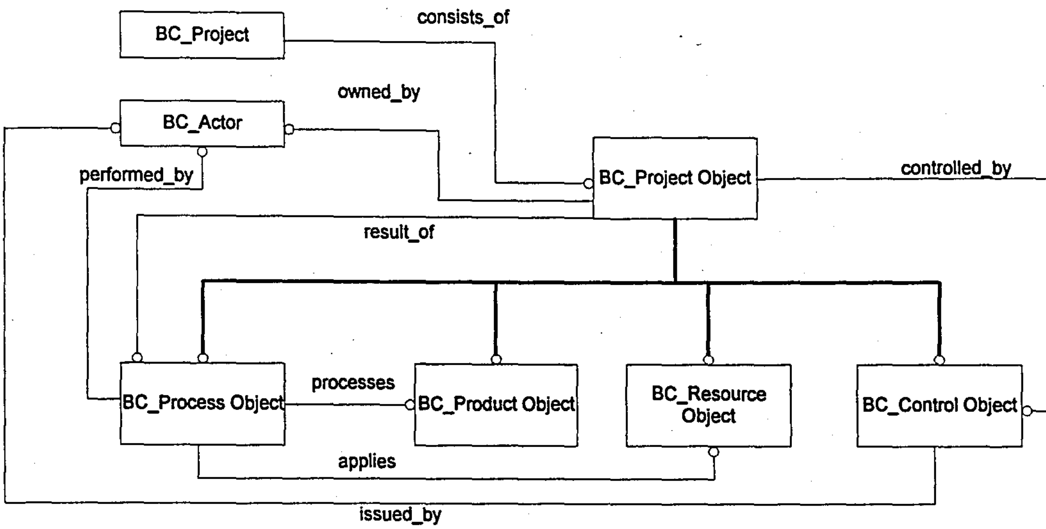


FIGURE 2.4. Basic Objects of STEP Building Construction Core Model

Use of knowledge-based applications to capture design codes, automate schedule generation is a popular research area, although with limited industrial success [19-20]. Addressing the problem of interoperability among distributed heterogeneous models and agents captures also the semantics of integration. In this context, not only the data, but the semantics of the project model, the design intent, are shared and all the applications are used as if all were single applications without changing the workflow and the data structure of the original applications. Current research focuses mostly on these aspects among project participants. Developing collaborative environments among project participants using distributed computer technology, Internet, and organization theory is also an active research topic [21].

The Enterprise Resource Planning (ERP) software represent the current state of the art of integration efforts in enterprises. Although they do not effectively implement computer integrated construction, they may lie as a component of future integration [22]. BAAN Project Module cover project functions including estimates, bids, planning, and scheduling, budgeting, purchasing, tracking, billing, and distribution. The data for all these functions are maintained and various applications are implemented using these data. **Figure 2.5** shows the applications in BAAN project module and its data exchange with other applications. The manufacturing system of BAAN can currently be integrated with

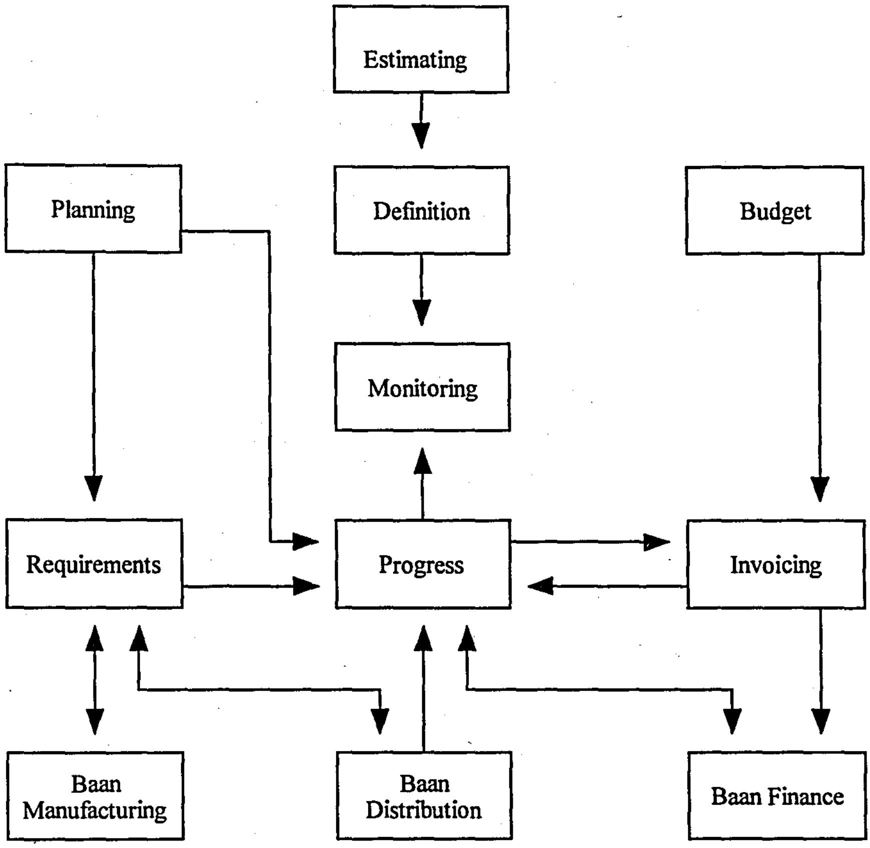


FIGURE 2.5. BAAN Project Module

manufacturing product data, from design stage to manufacturing and product support using Product Data Management subsystem. Similar improvements are ready to come for the A/E/C industry with the advent in prevalent CAD software, which propose or implement object oriented programming environments and links to database management systems.

2.3 Integrated Logistics Concept

An analysis of the evolution of integrated logistics concept in manufacturing will provide a valuable insight for application of logistics in construction.

Integrated logistics concept has evolved since 1960's from physical distribution in manufacturing where the aim was to manage finished goods distribution in a way to meet customer expectations at lowest possible cost [23]. The fragmented processes, each having narrow, functional basis, before 1960s came to be integrated under two common headings. *Materials management* was meant to be single manager organization concept embracing the planning, organizing, motivating and controlling all activities and personnel principally concerned with the flow of materials into an organization. *Physical distribution* was a broader range of activities including functions like freight, warehousing, materials handling, inventory control, customer service. Computerized modeling was started to be used for distribution, while MRP and large databases began to appear.

Then logistics organizations had experienced a transformation in the positioning of distribution and materials management functions by the early 1980's. Logistics constituted all the traditional functional responsibilities from raw materials procurement to product delivery [24]. It was the total range of activities concerned with the movement of materials including information and control systems, as well as several functions previously performed by marketing and manufacturing (production planning, sales forecasting, raw materials/work in process, and customer service). Internal integration of logistics was the main objective in this period. Information had become a key component in providing logistics services. Information technology allowed firms to further integrate logistics functions, compress time, and eliminate cost from the supply chain. The pace of change quickened in this period.

In 1990s, globalization became a growing trend and the growth of international trade has driven further changes in the logistics organization. The organizational structure emerging from logistics activities follow the pattern of external integration. The focus has changed to viewing the firm within the context of an overall chain of value-creating activities of which the firm itself is only one part, thus supply chain management. The supply-chain is a process where internal and external units in a company are put together to bring low-cost, high-value performance to the customer. Costs and risks are reduced, productivity is improved, resources are leveraged. Supply-chain management deals with the management of materials, information and financial resources across a network of firms that are involved in the design and production process. Supply-chain management recognizes the interconnections between materials, information and financial resources both within and across organizational boundaries and seeks systemic improvements in the way these resources are structured and controlled.

Supply - chain management needs a major reengineering effort in most of the companies. Customer service requirements drive the structure of the entire supply chain. It is essential to understand what customers demand and to develop a customer service strategy that can meet those expectations. Organizational structure and barriers within an organization is one of the main complexities through a supply-chain. Thus many companies have intentionally decentralized operational control of their business units and functions. Decentralized control refers to cases where each individual unit in the supply chain makes decisions based on local information [25].

As firms involved in all types of projects will stem from a more global and diverse base, and as the virtual or network form becomes more popular in industry, understanding the dynamics of coordination within networks will become more important. This is particularly meaningful for manufacturing organizations as it seems inevitable that, as they move more and more toward customized products and the increased use of suppliers for everything from design to distribution, manufacturing organizations will look, at the network level, more and more like construction project organizations [26].

There are specific characteristics of logistics applications that differentiate them from other information system applications [23]. Logistics applications are:

(A) very data intensive, because they must include information from all dimensions of customer, product, facility, logistics and project activity. For each dimension, there exists historical, current and planned values.

(B) Logistics applications have substantial interaction and dynamic interchange between coordinating and operating flows. Significant information exchange is necessary to achieve integrated coordination plans and operational activities.

(C) Logistics activities involve a high level of sequential processing for operational applications. The transactions are usually very structured in terms of initiator, receiver, data requirements, and processing sequence.

2.4 Logistics For A/E/C Companies

Construction materials management research is fairly new. A November 1982 report by Business Roundtable in United States defines materials management in construction as "the management system for planning and controlling all necessary efforts to make certain that the right quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed" [27]. Prior to the publication of this report, very little had been written on the subject. Bell and Stukhart summarized the necessary attributes to develop materials management systems. There is however a growing awareness in the construction industry that materials management needs to be addressed as a comprehensive, integrated management activity [28]. The materials management process may differ significantly by construction type [29]. However these differences appear to be primarily in the form of approval requirements.

Establishing internal integration in construction is a prerequisite in successful external information exchange. The primary benefits of an internally integrated information environment include the reduction of duplicated effort, minimized process rework, improved accuracy, a reduction of the amount of paper used, broader access of information and the ability to control the materials management process at the line-item level.

In construction there may be extra constraints in material management, imposed by the owner or by site conditions. Some examples may be restricted site access and laydown areas, use of multiple subcontractors, schedule compressions and changes, cash flow restrictions, frequent design changes. There is not any industry standard coding system devised for either the bulk materials (e.g. standard pipe and fittings) or engineered materials (e.g. pumps, fabricated pipe and tanks) [27]. As a result, coding systems and specifications established by individual design firms must somehow be unified and transferred to the contractor's materials management system.

Electronic Data Interchange (EDI) has many identifiable benefits in administrative business processes, including reduced paper cost, improved information processing accuracy, the elimination of postal expenses, a potential reduction of inventory and the probable reduction of labor and resource requirements. A construction company reported 82 percent of annual requisitions to be standard catalog items [29]. By use of EDI, manual purchasing cycle time of 23 days was reduced to degree of 8 days. An estimated $389,000 savings in processing cost was identified that was directly attributable to EDI. It was further estimated that by the time the utility had 90 percent of its purchasing volume integrated into the EDI application, $1,000,000 in annual cost savings would be realized [30].

Similarly, the bar code technology produces tangible cost-saving benefits for the construction industry [31, 32]. The main benefits of bar coding are the elimination of human error and a significantly more efficient data entry process. The more automated the overall system, the more valuable bar codes are, because they provide reliable, fully automated data capture and real-time verification. Various symbologies exist for bar coding, but Code 39 symbology, which permits the coding of both numeric and alphabetic data, has evolved as a standard in the automotive, defense, manufacturing and construction industries. A bar coded document management system at a nuclear plant reduced database data entry time for 2 hour per day to 7 min per day. An aerospace firm increased inventory accuracy by 20% in 6 months, which resulted in a $2,200,000 savings in reduced carrying costs and a $1,000,000 savings in reduced surplus inventory [32].

A relatively old research conducted by Construction Industry Institute revealed that 6 percent of craft costs can be reduced using an effective materials management system [33]. Materials and equipment account for 50-60 percent of total construction costs.

On projects lacking site materials management system, craft foremen have reported spending as much as 20 percent of their time hunting materials. Comprehensive integrated computer-aided systems that track bulk materials line items and provide information for craft work planning produces an addition of 4 to 6 percent savings in craft labor costs. Moreover a computer integrated materials management system reduces bulk materials surplus form a range of 5 to 10 percent to 1 to 3 percent of bulk materials purchased.

There are case studies in the literature for integrating materials management into project management information systems [34-36]. However, these studies generally do not deal with intensive logistics analysis and lack the effective tracking of materials through the supply-chain.

3. PROBLEM STATEMENT

An efficient modeling representation for enterprise-wide construction information should include logistics as a vital part of this representation. This model should effectively integrate with the emerging technologies. Construction information research done to date established many theoretical success, but implementation in real projects with concrete representations are still lacking. Especially the prevalence of 3D CAD with object oriented structure, database management systems, Internet, and knowledge based systems allows the effective integration.

The modeling view of a contractor company involved in both design, fabrication and construction is represented in this study to cover activities related to logistics taking place among project participants during the construction project. This view has the advantage of more consistent project material and cost coding, and also company procedures. There would not be much difference in representing the case of partnering and joint ventures between corporations when participants agree on the project structures and coding representations.

From logistics point of view, project implementation in construction still can not take advantage of the supply chain integration. A single company can be involved in both manufacturing and construction. Also integration of many distinct partners of the supply chain is necessary. The role of the emerging technologies should be sought and a information framework should be defined. This structure should be open, extensible and flexible, considering the ever changing nature of the 90's. Moreover, this framework should be as general as possible, although every project is distinct.

Although construction firms have had long experience working within the network form, their experience has not been entirely successful. Delays and cost overruns are common. In large part, these problems stem from poor coordination of the activities of firms, which, in turn, is due to a limited willingness to share information and the lack of a tool to assess coordination needs and to quantify benefits of increased cooperation. The performance management tools for logistics implementations are not clearly specified.

This study develops an architecture for integrated logistics system for construction enterprises. **Figure 3.1** shows the overall picture of this study. The functions considered are requirements planning, purchasing, site-warehouse materials management, transportation management, human resources management, distribution, cost control for logistics and performance management for logistics operations. Purchasing is a key activity for logistics since it handles the inbound material flow for the company and the projects. Transportation management coordinates material deliveries and ensures that goods move from point of departure to the job-site. Warehouse materials management arranges the receiving, storing, handling of materials and issuing them to the projects. Site materials management deals with the in-site use of these materials. Human resources logistics are also included in this study as human factor is considered as the most important resource in a company and its relations with logistics are so tight that it can not be separated in a complete logistics analysis. Distribution resource planning(DRP) deals with the needs of inventory storing locations and ensures that supply sources and storage locations will be able to meet the demand. The cost control for logistics uses the work packaging model to control the resource costs during a project. Finally performance management for logistics operations provide the necessary measurement criteria for the performance of the activities.

For the modeling methodology, ARIS approach is used in this study. The logistics functions are divided into individual views, which makes it easier to model the process structure of the whole enterprise. Requirements, design and implementation of the construction logistics functions are explained. Informix Workgroup Server relational database management system, Informix New Era and Microsoft Visual Basic development environments are used for implementation.

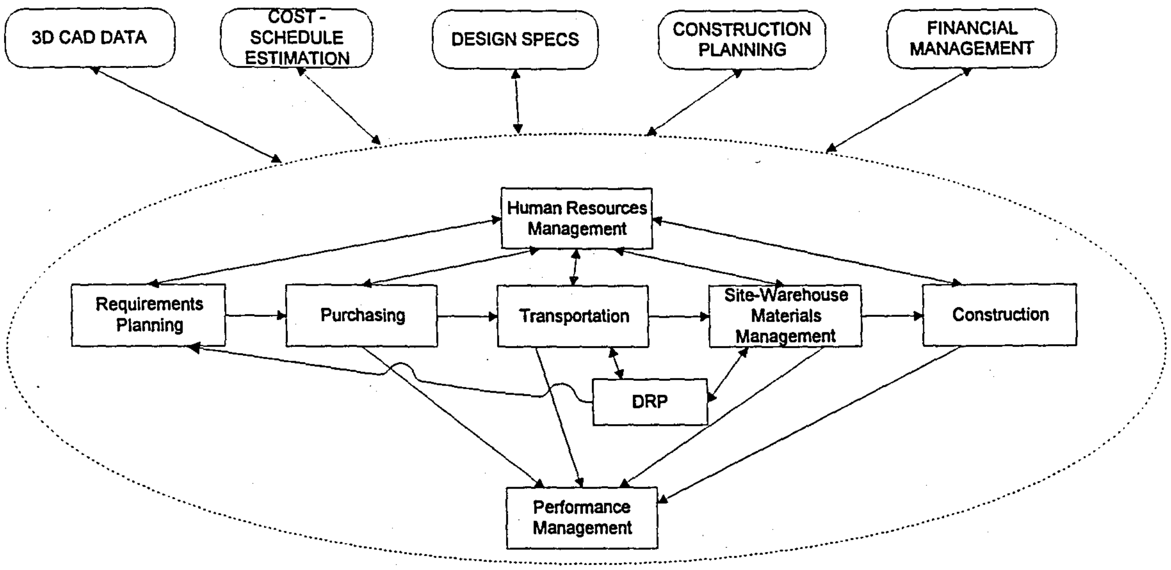


FIGURE 3.1. General Outline of the Scope of Study

4. ARIS MODELING METHODOLOGY

4.1 Process Representation Methodology

Architecture of Integrated Information Systems (ARIS) approach by Scheer [37] was applied as a methodology for process representation in this research. ARIS is a business processes modeling tool which is currently one of the most widely used one. This approach divides the model into views that represent discrete design aspects and can be handled independently. The overall picture is represented in the **Figure 4.1**.

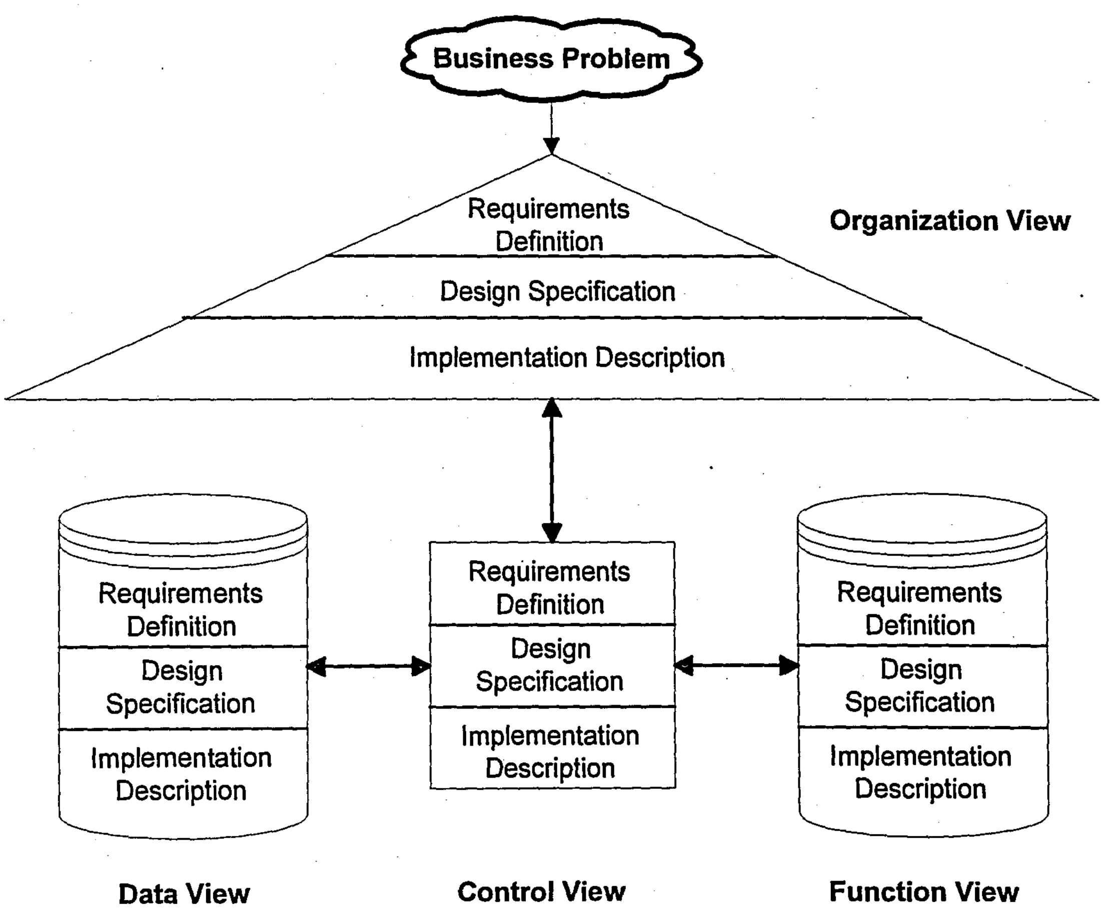


FIGURE 4.1. ARIS Architecture

Developing a model for business processes is a highly complex activity. Processes, activities, events, conditions, users, organizational units and information technology components and their interrelationships severely complicate the design process. To simplify the design process, the model is divided into different views and each individual view is described using specialized methods. Relationships within the views are very high and the relationships between the views are relatively simple and loosely linked.

Regarding this approach, static information, conditions and events form the *data view*. The functions to be performed and their relationships form the *function view*. The structure and relationships between users and organizational units constitute the *organization view*. Dividing the initial problem into individual views does reduce its complexity, but the relationships among these views must be represented. This is done by the *control view*.

Each of the views are represented by three levels based on their proximity to information technology. The *requirements definition* describes the business application to be supported in such formalized language that it can be used as the starting point for a consistent translation into information technology. At the *design specification* level, the conceptual environment of the requirements definition is transferred to the categories of the data processing environment. In the third step, *the implementation*, the design specification is transferred to concrete hardware and software components, and physical link to information technology is established.

4.2 Description Tools for Requirements/Design

4.2.1 The Requirements Definition

Although not included in the original ARIS architecture, data flow diagrams (DFD) are also developed for the system in this study. These diagrams are used to provide an initial overall view for each of the function - data relations and cross checking the developed ARIS system architecture. Data flow diagrams are simple but powerful graphical diagrams that are easily understood. DFDs may be drawn at a variety of levels. Level-0 (context) diagram shows the entire system as a single process. Level-1 DFD shows the major functions within the system and how they interconnect. Each level-1 process can be broken down to form a series of level-2 DFDs, and they may further be broken down to lower level of details. In this study, level-2 DFD is the lowest level prepared for the system.

There are five symbols, shown in **Figure 4.2**, that make up a DFD. These are data flow, physical flow, data store, external entity, and process [38]. A *data flow* shows the flow of data from a source to its destination. *A physical flow* shows the flow of material from source to destination. Physical flows are included to aid communication, only in the initial set of DFDs. A *data store* is a stationary data flow; it is generally a database file awaiting processing. To prevent DFD from becoming complicated, the same data store may be repeated several times on a DFD. The *external entity* represents a source or destination of a data flow which is outside the system boundary. The *process* represents a transformation of data flows. Processes are drawn as rectangular boxes with descriptive tile that contains an identification number and possibly a short identifier for the location of the process.

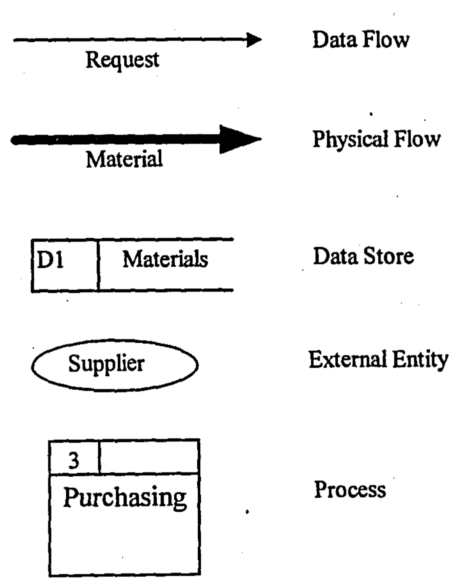


FIGURE 4.2. Data Flow Diagram Symbols

In the original ARIS architecture, function view represents the functions in each process such that break-down of complex functions into sub-functions reduce the complexity. Function trees are chosen here to represent the hierarchical structure of functions. Functions are represented by boxes, and can be divided into several hierarchy levels. The division process ends when it no longer makes sense to divide them from a business point of view. **Figure 4.3** demonstrates an example portion of a function tree. The ordering function is divided into subfunctions, one of it being the purchase order transmission, and it is further broken down to lower level subfunctions. Function trees are generally self-explanatory.

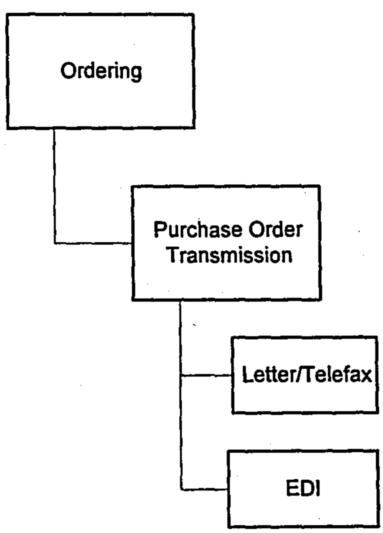


FIGURE 4.3. An Example Function Tree

Data View (Conceptual model) in the requirements definition describes the essential semantics of system data. Semantic modeling captures the data to represent the meaning. The steps involved are identifying useful semantic concepts, devising corresponding symbolic objects, devising corresponding integrity rules and operators. An entity relationship model is a semantic modeling tool, described originally by Chen, which consists of entities and relationships between the entities. Anything that exists and is distinguishable is an entity. Entity sets have attributes and each entity is uniquely identified by the values of its attributes. Selection of relevant attributes for entity sets is important in designing an E-R model [39]. Each entity set models only one concept, that is entities with some common properties.

Relationships exist among entity sets. A relationship is represented as an ordered list of entity sets. Entity types are written in capital letters in this text. A real-world problem is represented basically in combinations of one-to-one(1:1), one-to-many(1:M) or many-to-one(M:1), and many-to-many (N:M) relationships, known as the cardinality of the relation. The cardinalities of the relations are shown on the line of the relations. Relationships are identified by merging the key values of the affected entity types. This research foregoes the (min, max) notation to specify the upper and lower limits for the number of permissible relationship instances a relationship may have, because it is hard to decide on this in a general framework.

The initial entity-relationship modeling has gone through many developments over time. The ones used in this study are generalization-specialization and aggregation. Generalization is used to group similar object types under one superordinate object type. The generalization can also occur in reverse, in which a generic concept is divided into subconcepts. Aggregation describes the formation of new concepts by combining the existing different object types. Aggregation is expressed in an ER model by the formation of relationship types. In this sense, a relationship type groups the entity types associated with it.

Figure 4.4 shows an example of an ERD. In this case MATERIAL and CONTROL ACCOUNT are entity types, whereas MATERIAL-CA ASMT was a relationship at the beginning, but it is transformed into a entity because of the n:m relation between the entities. Thus all the three entities are represented as tables in the relational database model. A relation (table) key is a set of columns whose values select unique relation rows. Relation keys can be made up of more than one column. An attribute is a key attribute if it is at least part of one relation key. It is a non-key attribute if it is not part of any relation key. In this study, the key and non-key attributes are not shown on the ERD diagrams. Instead they are referred to in design specifications shown in the **Appendix B.**

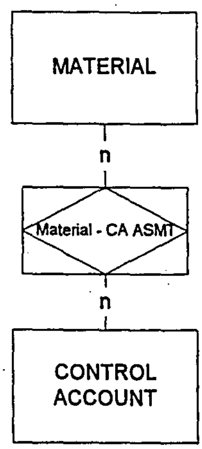
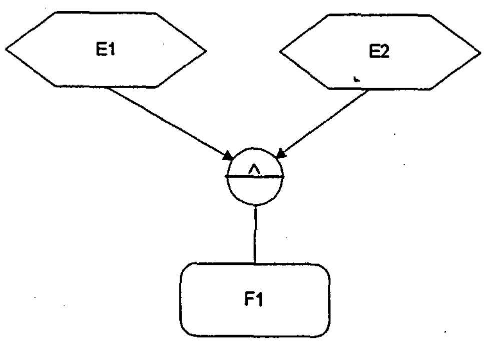


FIGURE 4.4. An ERD Example

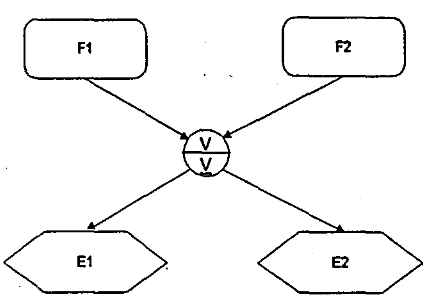
Organization View is the third view in requirements definition. In order for human beings to be able to handle complex social structures such as enterprises, these structures must be broken down into manageable units. The rules required for this process are referred to as organization. The principal task of the organization is coordinating as inexpensively as possible the communication needs that arise from breaking down a complex unit. The success of a project is greatly influenced by the organizational environment surrounding it.

Organizations in a construction project are more complex, since distinct companies, as well as many subcontractors involve in a project. There are two basic organizational structures normally considered in project management. On a task force, the project personnel are assigned to one specific project on a full-time basis. They all report directly to the project manager. The task force concept can be used on projects that are large enough to support dedicated project personnel. In a matrix organization, the project manager and certain key second line managers are assigned to be full time, the remainder are supplied on an as-needed basis from a central organization. The matrix is efficient for a project that cannot support a full complement of project personnel.

Control view deals with links between functions, organization and data. Combining functions with data is one of the most important control views. An event can be defined as the occurrence of an object or the change in a given instance of an attribute. Events are limited to one point in time. Event driven process chain (EPC) diagrams create a link of conditional event networks. Logical operators "AND" ($\wedge$), "OR" ($\vee$) and "exclusive OR" ($\underline{\vee}$) describe the link between the events. **Figure 4.5a** and **Figure 4.5b** shows two EPC diagrams. The first one implies that if both E1 and E2 events occur, then function F1 starts. The second is that if the function F1 or F2 is completed, either the event E1 or the event E2 happens.



(a)



(b)

FIGURE 4.5. Two Examples of EPC diagrams

Process chain diagrams (PCD) provide a condensed form of all ARIS descriptive views (functions, organization, data, and their interaction). Process chain diagrams are primarily geared toward representing the interaction between all ARIS components. The logical interdependencies can be illustrated with linking operators. **Figure 4.6** shows an excerpt from an PCD for construction logistics. Organizational units responsible for functions are shown with a line between them. Events may also be included in PCDs to complete the overall view.

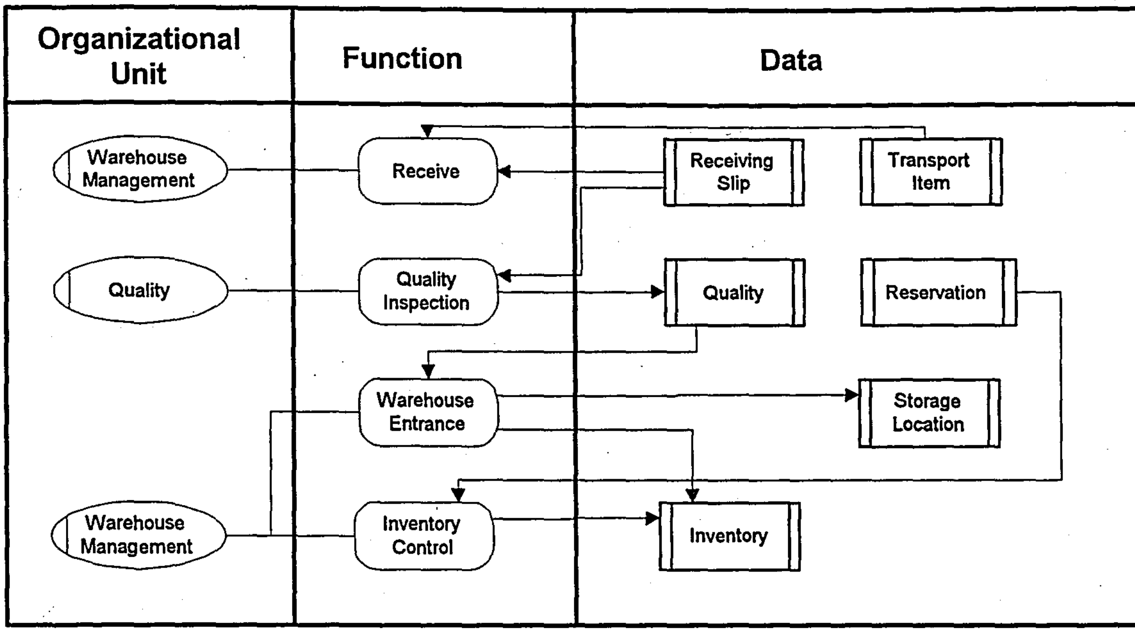


FIGURE 4.6. An Example PCD Diagram

4.2.2 Design Specification

In the design specification, requirements definitions are adapted to information technology interfaces. The objective is oriented to the properties of the information technology.

Function view encompasses modules, control structures and screen forms design. A transaction is an interconnected sequence of interactive steps for processing a task. It has a great significance on the design requirement as it forms the basis for data integrity concepts. If there are execution errors, all data is returned to the status before the beginning of the transaction. Modules represent an aggregate concept for transaction, program elements, processing steps. One function of the requirements definition can be supported by several modules, or several functions by one module. A module may be interactive, i.e. expecting input from the user while processing, or batch, i.e. processing without user interaction.

User transactions are directed on the interactive transaction dialogs. Different presentation methods are used in on-line user dialog for entering transaction data. The most common methods are menus, commands or forms. A menu system presents the user with a set of actions and requires the user to select one of those actions. Commands and prompts ask the user for specific inputs and on getting the input, responds with some information and requests for some more input. When screen forms are used, form is presented on the screen and the user is requested to fill in the form. The advantage of screen forms over menus or commands is that the data is entered with fewer screens. Current improvements in software development tools allow for easy implementations of designed screen forms and generate events for user actions. **Figure 4.7** shows an example screen form for material inventory information entry.

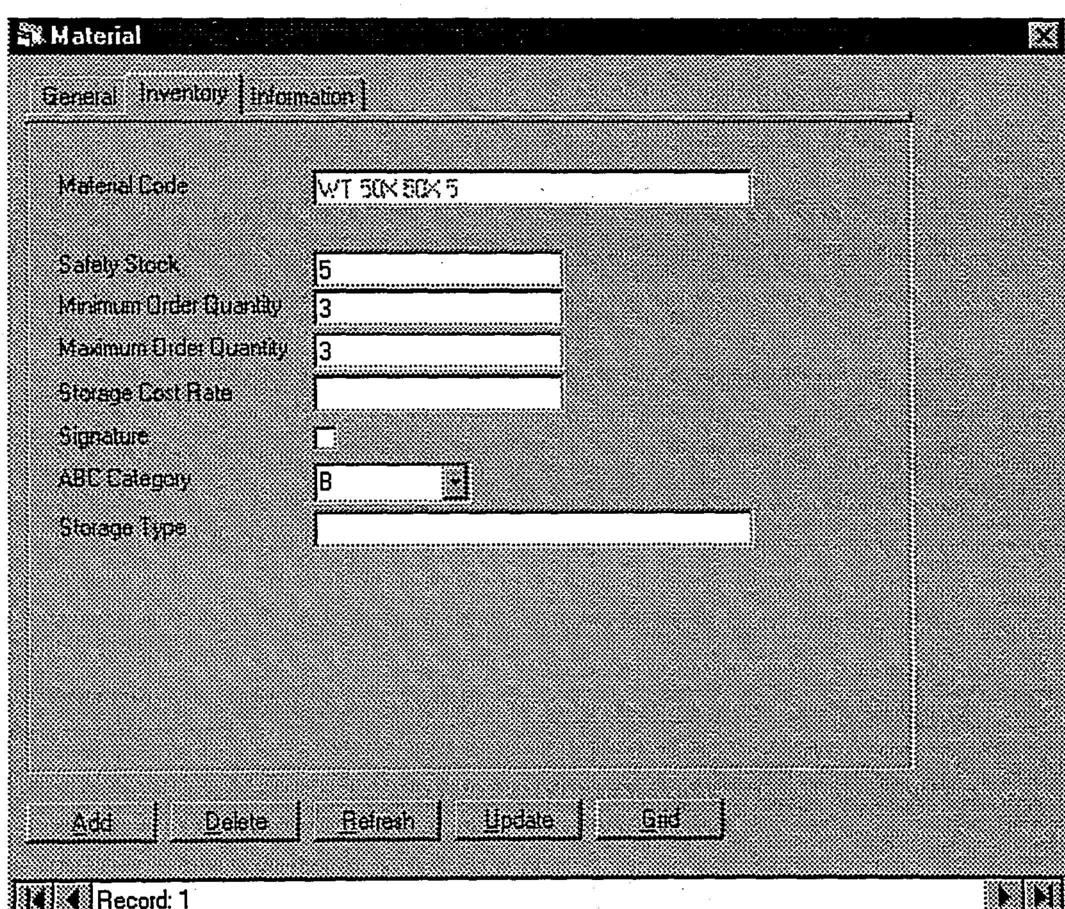
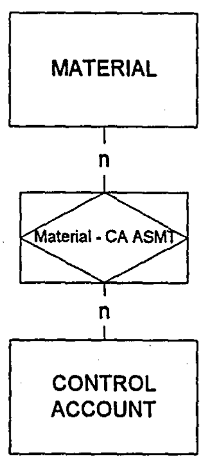


FIGURE 4.7. An Example Screen Form

Organizational view is illustrated with the network topology. The organizational structure produces demands on communication and coordination needs. Within the framework of design specification, this is represented by network topology. Many participants for a construction project, sharing project models and databases, require efficient network structure. For computers on a proximal area, local area networks (LAN) may be sufficient, but for remote participants, wide area networks (WAN) may be the only possible solution. Internet and WWW are evolving to become a standard solution for remote, distributed participants. Distributed processing on the other hand means that distinct machines can be connected together into a communications network such that a single data processing and data storage tasks can span several machines in the network. Communications between the various machines is handled by some kind of network management software.

The data view is the description of the approach in which the concrete database system can be built. This system is built upon the entity relationship diagram developed in the requirements definition. Relational, object oriented, network databases may be the alternatives. In our case relational database system was chosen. In a relational system, the data is perceived by the user as tables. A table is an array of data items organized into rows and columns [39, 40]. The reason that such systems are called relational is the term "relation" is essentially just a mathematical term for table. Each column of a table stands for one attribute, which is one characteristic feature of the table, and each row of a table stands for one instance of the subject of the table. The operators that the user applies generate new tables from the old ones.

To convert an E-R diagram to a set of relations, simplest way is to replace each set in the E-R diagram by a table. Thus each entity set and each relationship set becomes a table. The name of the set becomes the table name, and the attributes of the set becomes the table columns. **Figure 4.8** shows an example conversion. MATERIAL table has *mat_code* as a key. CONTROL_ACC table has a compound key having project_code, control_code as key attributes. MATERIAL - CA ASMT table is developed to compensate for n:m relation between the entities with compound keys *mat_code*, *project_code* and *control_code*. This table has *mat_amount* attribute to store specific material amount assigned to each control account. In **Appendix B,** relational tables which are converted from ERD diagrams are shown. Tables are represented by rectangles. The item on the top of each rectangle is the table name, followed by key attributes, and then non-key attributes divided from key attributes by a horizontal line.



MATERIAL

material_code	unit	unit_weight	safety_stock	signature
ELB11	ea	0.2	15	No
ELB12	ea	0.18	5	No
ELB13	ea	37	5	No
ELB14	ea	20.3	5	No

MATERIAL_CA

material_code	project_code	control_code	mat_amount
ELB11	20	20510	25
ELB11	20	20520	8
ELB11	20	20530	10
ELB11	20	20540	30

CONTROL_ACC

project_code	control_code	obs_code	est_start	est_end
20	20510	111	07-Jul-97	14-Jul-97
20	20520	111	21-Jul-97	18-Aug-97
20	20530	111	04-Aug-97	18-Aug-97
20	20540	111	18-Aug-97	29-Sep-97

FIGURE 4.8. ERD Diagrams to Relations

Normalization is a theory based on sound mathematics that specifies how we should construct tables to avoid data redundancies. A number of normal forms have been defined for relations. They are known as first normal form (1NF), second normal form(2NF), third normal form(3NF) , and Boyce-Codd normal form. There are two main constraints met by normal relations. First, relations must be flat, i.e. all of the column values must have simple values, not group of values. Second, normal relations must not contain redundancy. A correct entity-relationship diagram is in the third normal form, if no redundant attributes are added.

In order to control a process chain, subprocesses must be initiated at the right time and assigned to appropriate organizational units. Action messages and triggers facilitate the information flow between the processing programs and the users. A trigger causes an action to occur when an premise initiates it. Triggers are used in database systems to maintain consistency.

4.2.3 Implementation Description

In the implementation, the design specifications are transferred into concrete information technology products. Performance is the most important criterion in this phase. To achieve computer integrated construction, interfaces and bindings should be defined in the implementation. The implementation is explained in Chapter 6.

In the function view, the subject contents developed so far are transferred to concrete data processing (DP) programs. This involves code generation, use of CASE(Computer Assisted Software Engineering) tools and report generations.

The data view is the transformation of the data model into concrete database system. A data definition language (DDL) is used to transfer the relational model into relational database management system.

In the organization view, the network topology is implemented using hardware, software and network protocols. Ethernet, ATM, or token ring might be alternatives for network implementation.

The control view in the implementation links components and modules developed in design specifications, concretized in implementation views. Thus the programs, network structure, data, possibly 3D CAD model, are all linked to achieve an integrated structure.

5. PROCESS ANALYSIS OF LOGISTICS FUNCTIONS IN CONSTRUCTION

The following discussion will explain the general process analysis for logistics functions in construction. Requirements and design specifications are described in this chapter. Implementation is explained in the Chapter 6.

The logistics in construction should be a component in a whole integrated structure. **Figure A.1** is the context, or level-0 DFD for construction logistics, showing overall inputs and outputs. **Figure A.2** shows the general outline of the system in level-1 DFD diagram. Materials defined and standardized under material definitions are used to generate the CAD data and that data is used to generate the bill of quantities for the project. The requirements planning checks the conflicts, material availability using DRP, allocates costs, generate requirements. Purchasing generate inquiries, take quotes and send purchase orders. The supplier prepares and sends the material. Meanwhile the order is expedited by purchasing department. Transportation management coordinates the material deliveries. After the material is received, it is added to the inventory in the warehouse. The material may later be issued for construction or return from the field. Human resources management is concerned with the human resources in all of these functions. All the activities in warehouse management, purchasing, transportation, and control accounts are evaluated in performance management function. **Figures A.3** to **A.9** shows the level-2 DFDs for each of the functions. **Figure 5.1** shows the function tree for the overall construction logistics. Each of these items under the tree will be explained in detail.

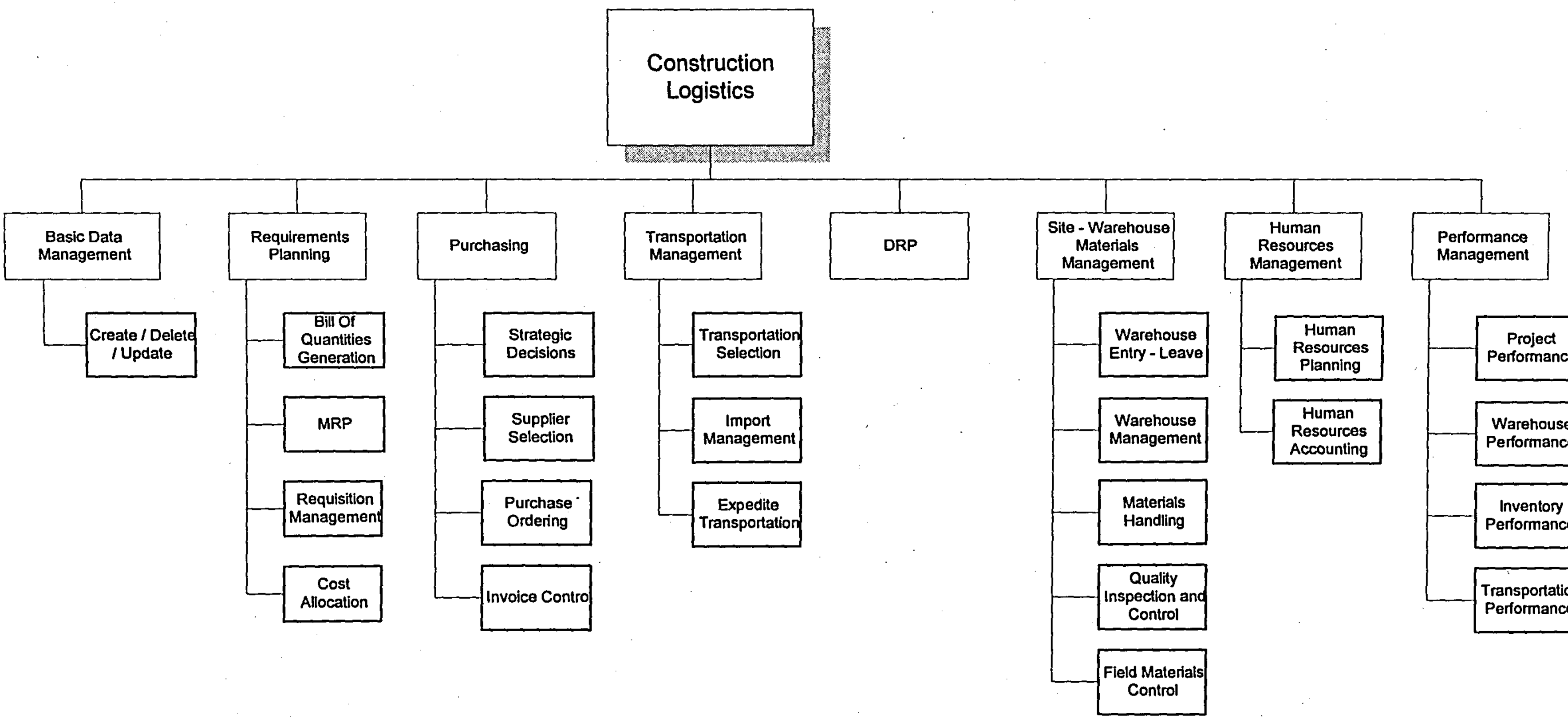


FIGURE 5.1. Function Tree for Overall Construction Logistics

5.1 Basic Data Management for Logistics

The data structure for the system assumes the wealth of information entered since the beginning of each project. The analysis for the construction environment is not complete here since project management activities outside the scope of logistics are not analyzed in this study. However, the essential entities are represented. Some of the data come from the estimating phase and some shape up during preliminary design. The main entities for basic data management are PROJECT, MATERIAL, WORK BREAKDOWN STRUCTURE(WBS), CONTROL ACCOUNT, ORGANIZATIONAL BREAKDOWN STRUCTURE.

A single project instance is defined for each project, which is the main repository for project related data. This entity is related to many of the entity types in the model. The master MATERIALS entity type contains all the material specific information such as the master data (the material code number, its description, specification, and the unit of measure, etc.), material properties (unit weight and area), planning data (safety stock, reorder inventory level, average lead times, etc.). A standard coding and tagging scheme is developed for materials and the same coding structure is used throughout the project. The consistency of this scheme among different projects and project participants is very important. In some materials industries, e.g. structural metals and electrical supplies, standard product designation schemes have been developed. In other industries, industrial pipe, valves and fitting, for example, industry accepted coding schemes do not exist. When working with systems void of common numbering schemes, the facility designer will initially load the system with commodity codes that correspond to his own design specifications.

On a construction job site, material resources can be separated into three categories. Bulk materials are manufactured according to specific generic industry standards, specs and codes. Examples are concrete, pipe fittings, valves. Prefabricated materials are usually fabricated outside the job site. These are suitable for bill of materials and MRP representation. Precast concrete items, prefabricated structural steel elements are included under this category. Consumable materials do not add much to cost, but allowance must be made for them. Welding materials, small tools, safety equipment are examples. Identification and tracking of components of construction process itself is also important. For example, formwork to support curing concrete, scaffolding to support workers are not part of the structure, neither equipments but should be identified in the system.

Planning and budgeting in the work-packaging model requires the use of a WBS approach early in the project life cycle. WBS is the hierarchical representation of all activities in a project. A typical WBS first divides a project into major process or service systems and facilities. Each system and facility is then further subdivided into activities which must be accomplished to complete the systems. Work must be scheduled in accordance with the WBS. In this study, control accounts approach was used [34, 35]. Control accounts are defined on the basis of WBS; thus CONTROL ACCOUNT entity is a specialization of WBS. Budgets of resource consumption and costs must be prepared for each CONTROL ACCOUNT entity. Then via logical sequences between control accounts, each control account becomes an activity on the activity network for scheduling.

Also, organizational, functional responsibilities are assigned to each control account established at the desired level of detail on the WBS. To achieve this, the organizational structure of the company and the specific project should be defined. This definition is done under another breakdown structure called ORGANIZATIONAL BREAKDOWN STRUCTURE (OBS) entity type. These structures are implemented in this data model and integrated with all functions and processes of the project. Cost and schedule control shares budgeted cost, resources, and quantities, and they share actual resources employed and quantities produced [35]. Therefore all of the costs associated with materials are combined under control accounts to integrate the cost and schedule within a project. PROJECT entity is related to both OBS and WBS.

Relational table structure of basic data in the system is shown in **Figure B.1**.

5.2 Requirements Planning

5.2.1 Requirements Definition

For a construction project, material takeoff is performed to produce the bill of quantities. The bill of quantities are generated from design data automatically, if the computer aided 3D CAD systems are used. This bill of quantities file is further elaborated to link material quantities to drawing numbers or regions of the project. The bill of quantities are assigned to control accounts and stored under MATERIAL - CA ASMT relation.

Material Requirements Planning (MRP) can be implemented to integrate project material requirements with the fabrication plant. MRP is composed basically of gross requirements, netting, lot sizing and offsetting. The EPC diagram for MRP is shown in **Figure 5.2.**

Equipment planning is an important part of the requirement definition. A great number of equipment items are purchased, leased or rented for construction projects - both small and large. Such equipment is usually assigned a tag number so it can readily be identified throughout the life of the particular facility. Equipment list is developed early in the detailed engineering phase of the project. Field installation dates for equipment items are crucial for requirements planning.

5.2.2 Design Specification

Requirements planning functions are generally interactive. Plant MRP implementation is an example to batch processing. Some specific data in design specifications for requirements planning are combined with and shown under design specifications for purchasing .

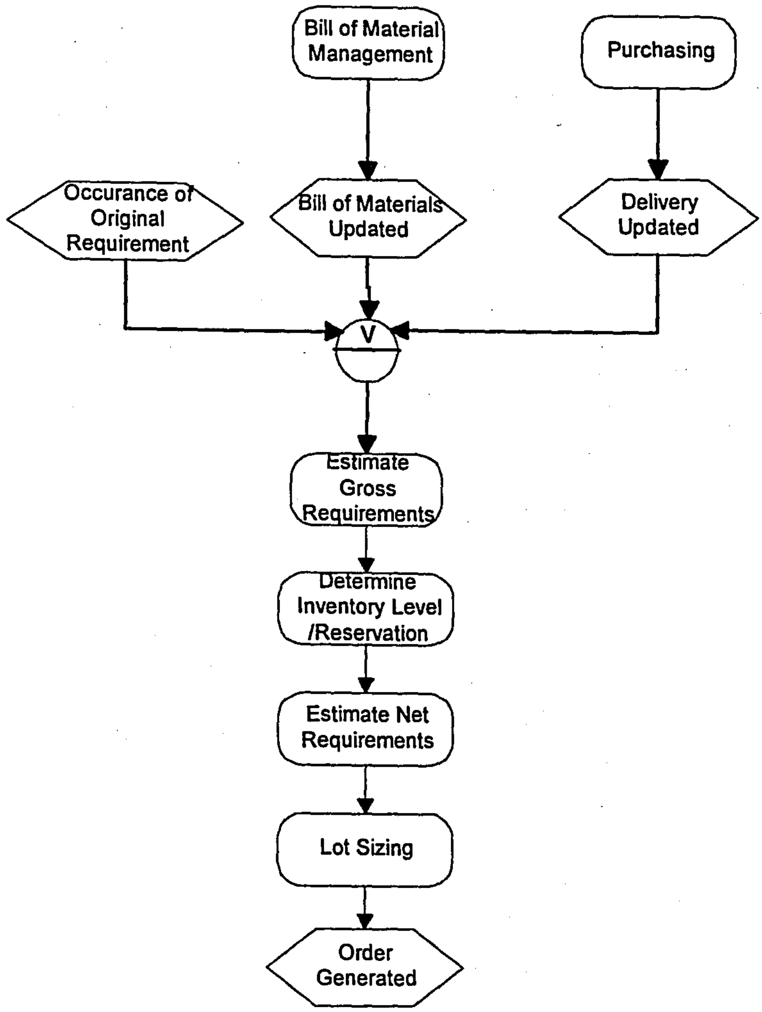


FIGURE 5.2. EPC for MRP

5.3 Purchasing

5.3.1 Requirements Definition

The importance of the purchasing function, also referred to as inbound logistics, is increasing for industrial enterprises. Essentially every department in every organizational unit can initiate a requirement, thus a purchase order.

The functional tree for the purchasing function is shown in **Figure 5.3**. Purchasing includes materials planning, supplier management, purchase order writing and dunning. Also receiving, invoice control and accounts payable data structures should be integrated in these functions to achieve non-redundant processing.

Data in purchasing is extracted from design, accounting and the suppliers in basic data management. Standardization is the link between engineering and procurement, which decides on the materials to be included and the representation structure of the material. The specifications definitions for industrial construction is classified under standardization. The material codings and project specifications should be prepared before in order to establish a consistent system.

For certain projects or project types, purchase orders may be issued for extremely large sums of money and thus require extraordinary control over purchase commitments. Additionally contract type (lump-sum versus cost-reimbursable) may affect this process.

Figure 5.4 shows the process chain diagram(PCD) for purchasing. The entity relationship diagram for purchasing is shown in **Figure 5.5. Figure 5.6** shows the event driven process chain diagram for overall purchasing. SUPPLIER is one of the main data in purchasing. It stores information about current, historical suppliers, as well as potential suppliers. SUPPLIER CHARACTERISTICS define the qualitative and quantitative evaluation of the supplier.

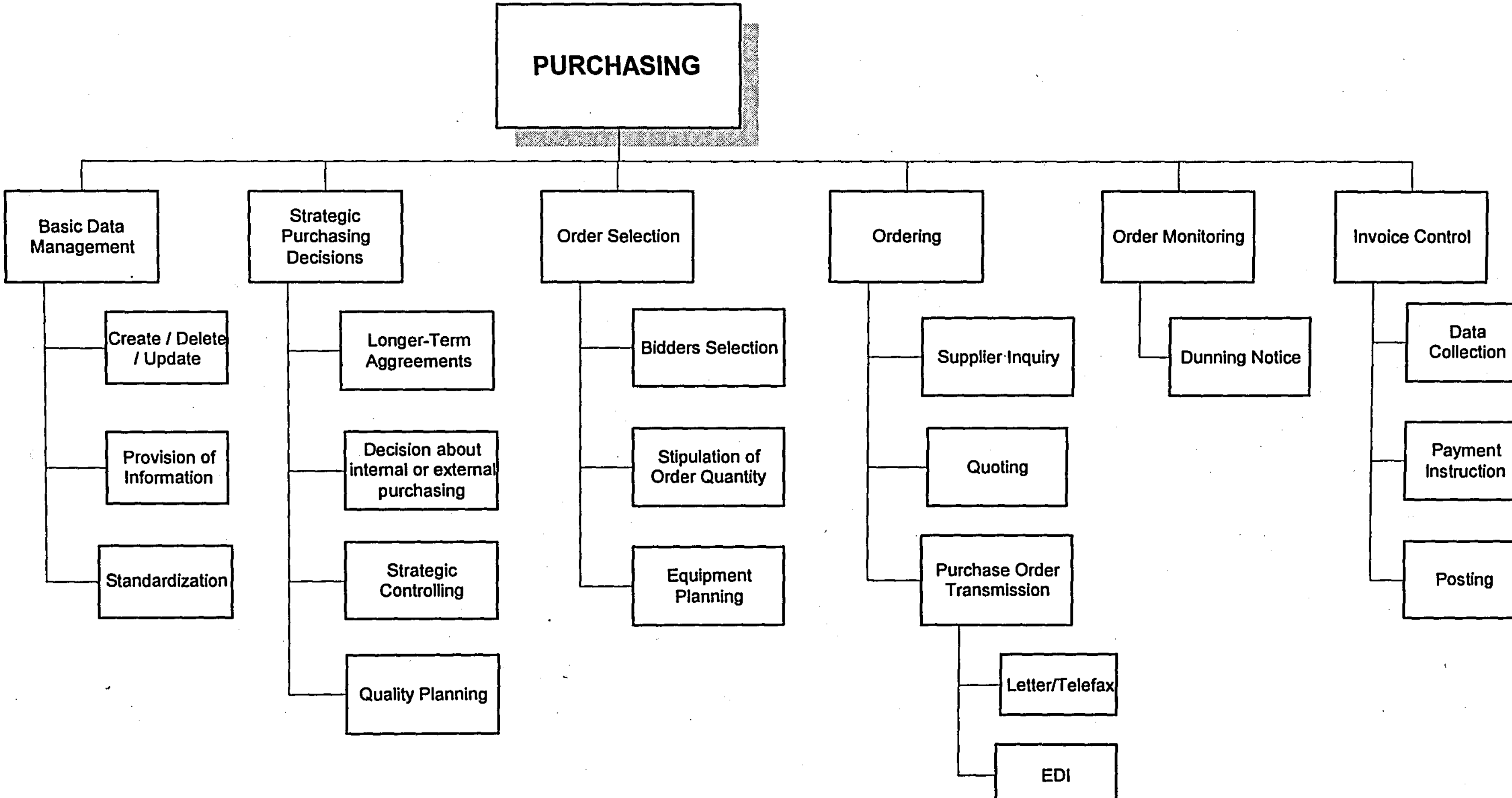


FIGURE 5.3. Function Tree For Purchasing

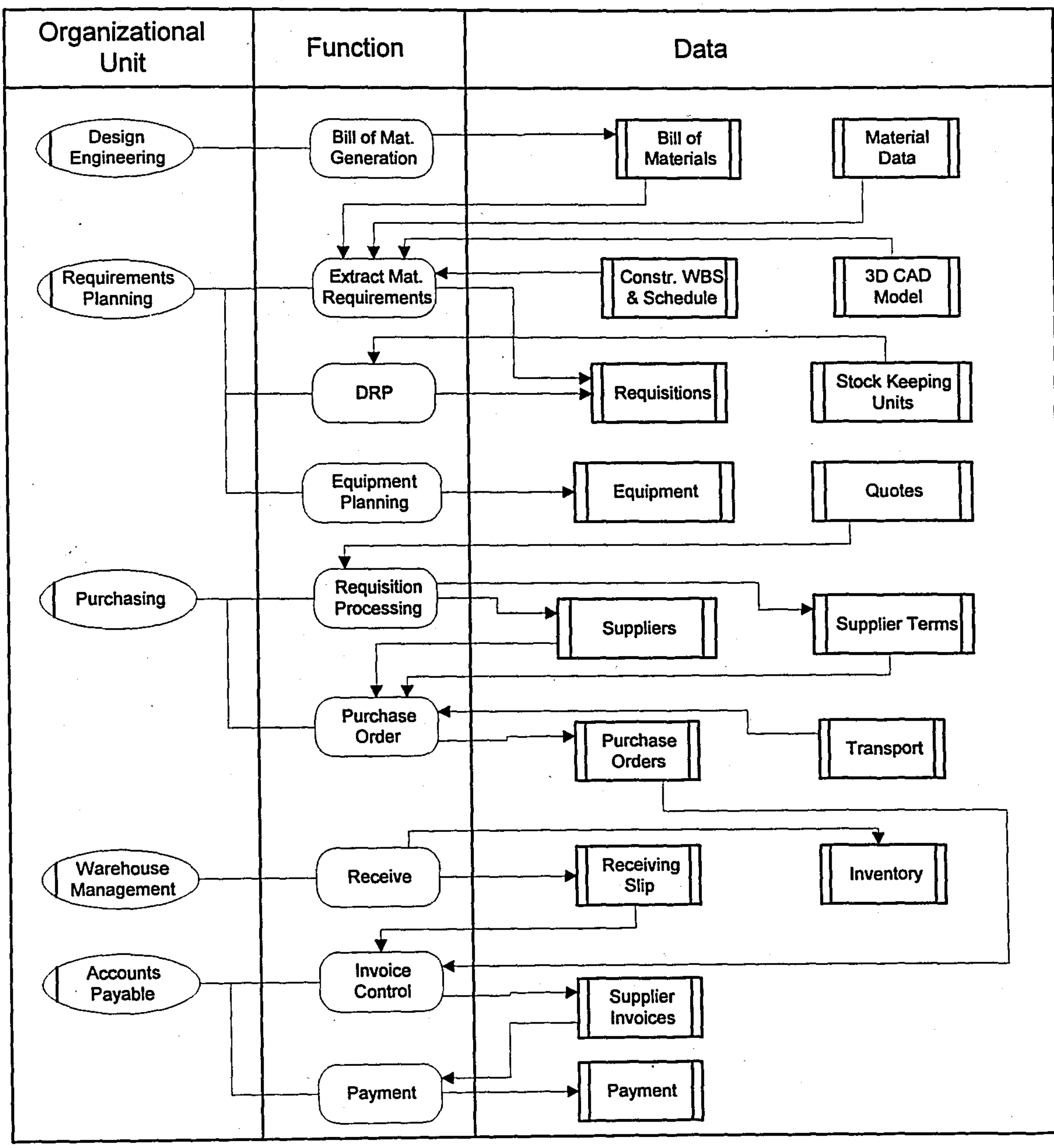


FIGURE 5.4. PCD For Purchasing

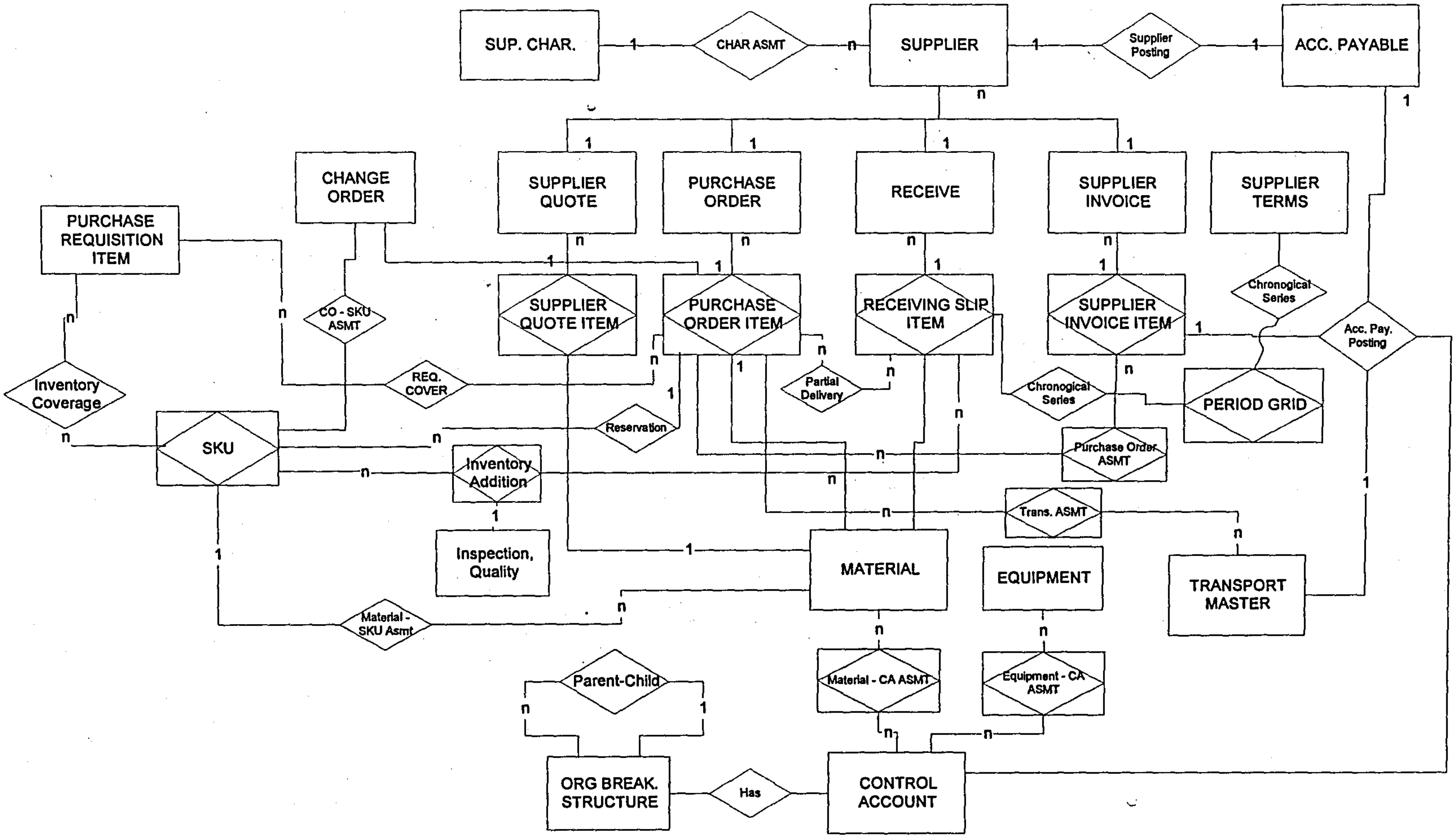


FIGURE 5.5. ERD For Purchasing

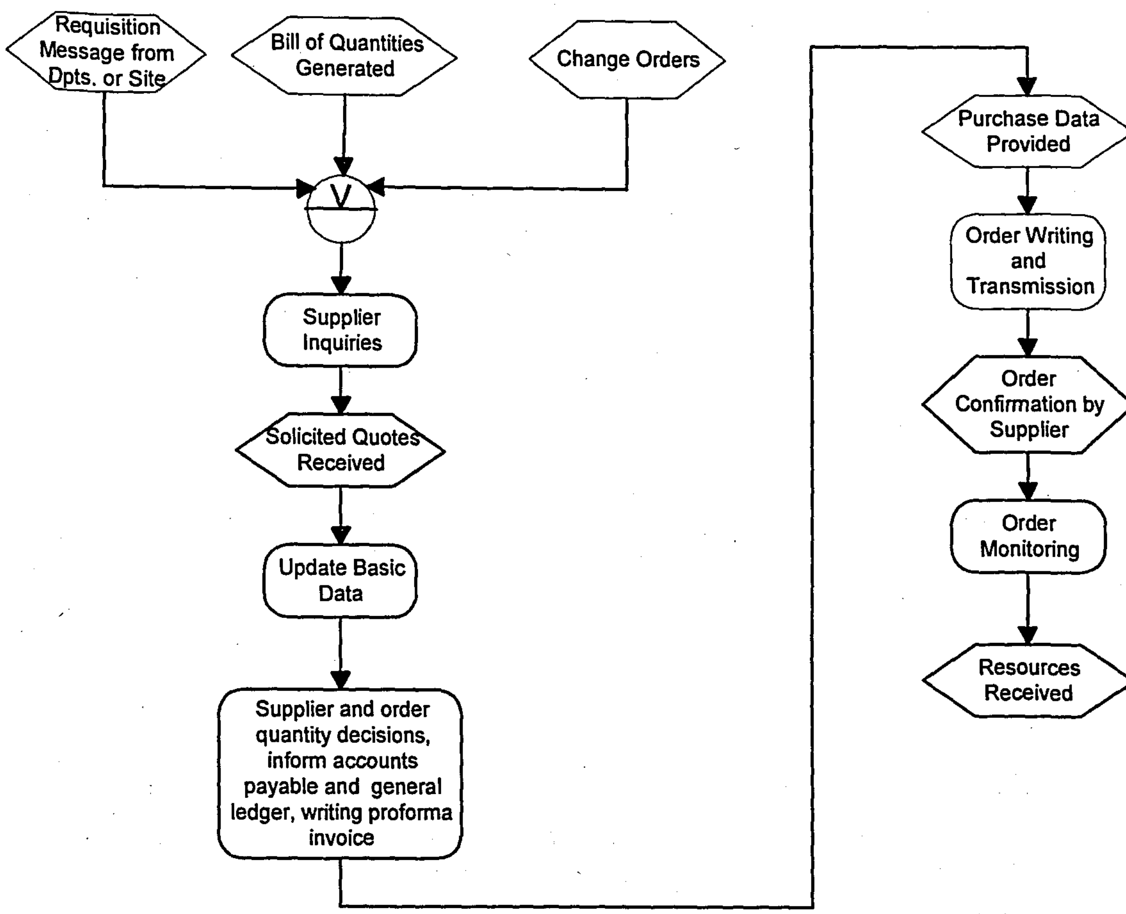


FIGURE 5.6. EPC For Purchasing

Before placing a purchase order, quotes are solicited from one or more suppliers. Supplier quotes are submitted in response to the inquiries. The purchasing department is responsible to decide upon the acceptance of a particular quotation. Each quote item relates to the quote and the material.

There are several documents used to exchange information between parties involved with purchasing, transmitted either paper-based or electronically. Inquiries, quotes, ordering, delivery plans, packing lists, invoices and quality control documents are among them. Individual document items may change over time. This is represented in this framework with entity type PERIOD GRID. Prices and quality ratings may also be available in chronological order. This may be important, for example, for tracking the evolution in purchase negotiations.

There are status attributes in the entities PURCHASE ORDER and PURCHASE ORDER ITEM that indicate whether a purchase order is still outstanding, a partial delivery has already been made or the purchase order has been completed. Transportation is highly related to the purchasing such that the timeliness and cost of the order depends on the transportation efficiency. There is an assignment of PURCHASE ORDER ITEM entity with TRANSPORTATION entity. A purchase order item instantly reserves the ordered, to be received material in the assigned warehouse.

PURCHASING REQUISITION ITEMS are gross values, so INVENTORY COVERAGE relationship with INVENTORY LEVEL allows net requisitions to be calculated.

Receiving is responsible for accepting the goods delivered by the suppliers, inspecting them for quality and quantity. Receiving of goods may be in a central warehouse or on a site in a construction project. Generally, goods sent by a supplier are accompanied by a packing list, which provides the basis for data entry or for receiving inspections. RECEIVING SLIP ITEM entity type holds the accepted and backordered amounts for the material. INVENTORY ADDITION relation with SKU in the warehouse aids the addition of the received materials. PARTIAL DELIVERY accounts for partial deliveries.

Following the receipt of the goods, invoice is the next document that has close overlaps with the previous data structures. An invoice consists of several invoice items each of which relates to a material. If the purchase order exists for the invoice, many of the data exists and therefore do not need to be re-entered. PURCHASE ORDER ASSIGNMENT exists between INVOICE ITEM and PURCHASE ORDER ITEM. Upon successful completion of the invoice review, the invoice amounts are released for payment. The interrelations are represented in the data structure as n:m relationships for the postings between SUPPLIER INVOICE ITEM and GENERAL LEDGER ACCOUNT as well as ACCOUNT PAYABLE ACCOUNT.

The packaging structure must be negotiated during supplier quoting. Packaging has direct influence on protection, utility, and communication of the material. Adequate protection to the material should be guaranteed during quotes. Hazards can occur depending on the type of transportation, storage, and handling used. The packaging of the incoming material is generally maintained until construction, so the utility of the package in the warehouse or the laydown areas is significant. The package symbolizes the product throughout the logistical channels. Correct identification of stock-keeping units, counting, special shipping instructions, and address represent the critical data. RECEIVING SLIP ITEM stores the necessary data about packaging like the package size, storage type, cube utilization.

Change orders are quite common in a construction environment. During project execution, new information may result from innovation or from the desire of the project team members to continually make improvements. Budgets, schedule, material amounts may change during a project. CHANGE ORDER relationship between PURCHASE ORDER ITEM and SKU allows for accounting the cancellation of purchase orders or other changes in the project that will affect purchasing decisions.

In this study, construction equipment purchasing is included to complete the purchasing function activities. Equipment purchasing process must start long before the field need date. Lease/Buy decisions of construction equipment is a more involved process and should be studied within the context of strategic capital investment decision making.

The purchasing function for construction projects is usually managed according to one of three distinct approaches: (1) centralized home office purchasing, (2) decentralized site or project based purchasing, or (3) a combination of these two approaches. The operative functions for quote processing, purchase order entry, and reservation are performed on the office level. Purchasing organizations are configured for comprehensive information distribution in order to combine optimal order amounts from different requirements for the same suppliers.

5.3.2 Design Specification

Purchasing functions deal with large amount of data. Thus there is a high amount of batch processing necessary, such as invoice posting, supplier unit conversion. The interactive applications include supplier selection, order quantity determination, supplier inquiry.

The ERD diagram for purchasing including requirements planning data is converted into relational table structure, which is summarized in **Figure B.2.**

For the organization view, direct network connections can be developed for inter-company data exchange. Electronic Data Interchange (EDI) is a form of electronic communication designed to permit trading partners in two or more organizations to exchange business data in electronic, structured formats. Typical transactions in construction materials management include requisitions, requests for quotations, purchase orders, invoices, shipping notifications, material lists, and payment transfers. EDI provides a medium to interconnect internal as well as external logistics functions. It eliminates the reentry of data and provides a quick and accurate means for electronically exchanging data. Secure transactions on the WWW will provide a low cost, higher access viable alternative to electronic purchasing.

5.4 Transportation Management

5.4.1 Requirements Definition

Coordinating material deliveries and ensuring that goods will move from the point of fabrication/manufacture/distribution to the job-site requires some very detailed planning. Inbound transportation is extremely time sensitive, and the ability to meet required delivery dates takes precedence over the cost of transport services. Accurate, integrated information technology for transportation has great benefits. During the 1980's the transportation and purchasing functions have progressed from virtually autonomous operating groups into strategically managed and integrated directors of the supply chain.

The main functions under transportation are route-carrier evaluation, transportation selection, transportation expediting, import management as shown in the **Figure 5.7**. **Figure 5.8** and **Figure 5.9** are the entity-relationship and process chain diagrams for transportation, respectively. The VEHICLES and ROUTES entity types are stored to keep the detailed data for transportation selection. TRANSPORTER FIRM is a subtype of SUPPLIER entity type. FREIGHT RATES are determined using the quotes received from transport firms. Route and transport firm selection is done on the basis of these data and criteria.

Main factors to be considered in transportation are safety, price, timing, and documentation. Transportation plan should consider field construction dates, thus the project schedule. The field need date is stored under PURCHASE ORDER ITEM. the TRANSPORT ASMT relation between PURCHASE ORDER ITEM and TRANSPORT MASTER provides the main connection with the purchased item and its transportation data. Many purchased items can be transported in a single transportation.

Large materials and equipment necessitate efficient communication with many diverse groups. The equipment can be broken down into elements and transported separately. Thus, the TRANSPORT ASMT establishes the relation between PURCHASE ORDER ITEM and TRANSPORT MASTER and is n:m.

Import management is an involved process. FOB is the abbreviation for "free on board" and primarily refers to when the ownership and title of goods pass from a supplier to a purchasing firm. Import management is represented by IMPORT entity type in the system related to TRANSPORT MASTER if the purchasing is from a foreign country.

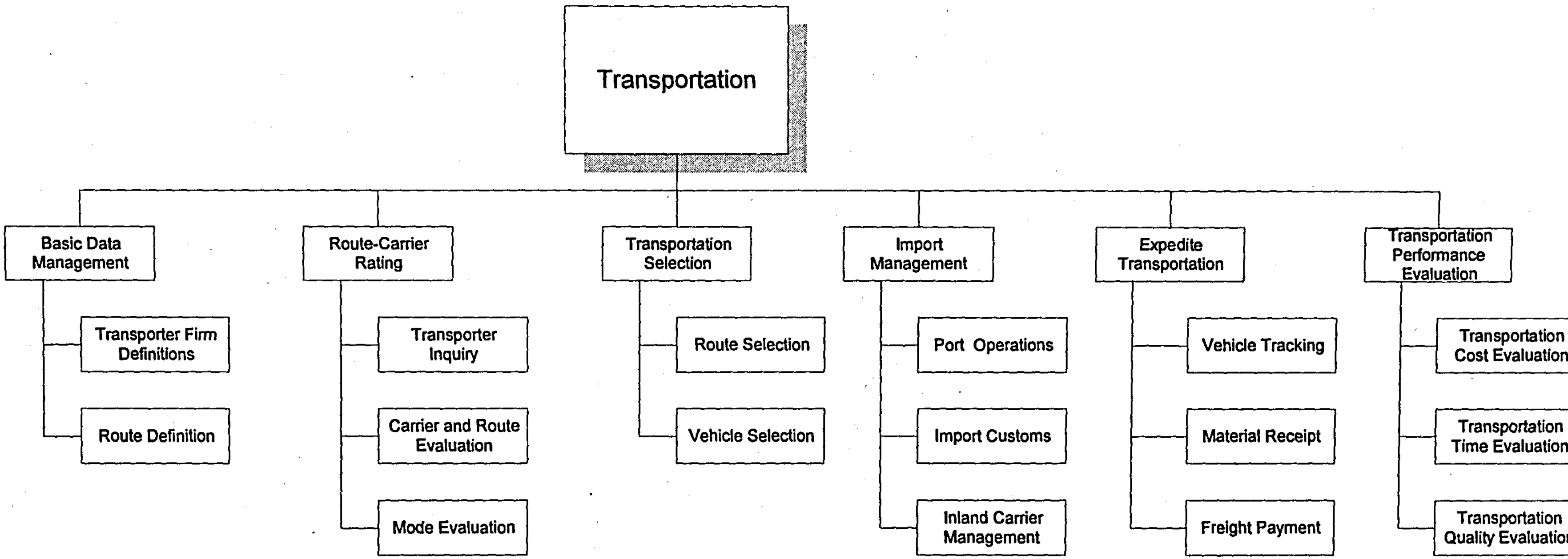


FIGURE 5.7. Function Tree For Transportation

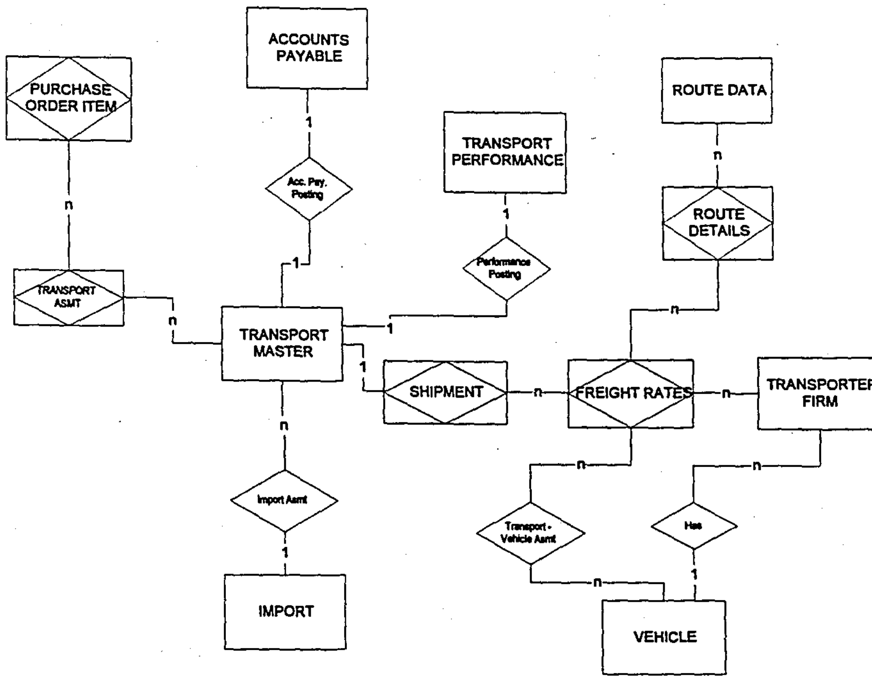


FIGURE 5.8. ERD For Transportation Management

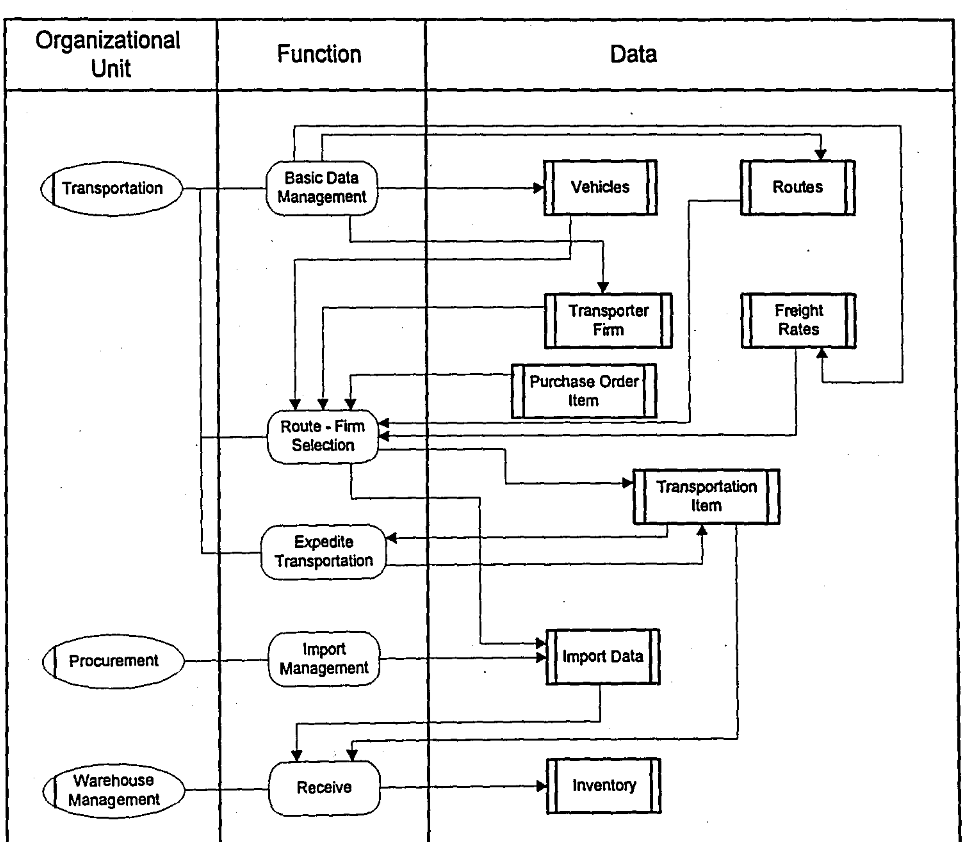


FIGURE 5.9. PCD For Transportation Management

5.4.2 Design Specification

Transportation functions have generally interactive processing, but route selection, transportation invoice posting are among batch processes. The transformation of the ERD diagram for transportation management into the relational model is shown in **Figure B.3.** The transportation planning may also employ EDI for information exchange with transportation suppliers.

5.5 Distribution Resource Planning

5.5.1 Requirements Definition

Distribution Resource Planning (DRP) is a management process that determines the needs of inventory stocking locations and ensures that supply sources will be able to meet the demand. DRP is defined as an individual function to explain it more thoroughly and seek its possibility of use for construction.

Distribution Resource Planning (DRP) is a powerful tool for improving distribution operations. Firms use DRP process to project when, and in what amount, individual stock-keeping units(SKU) will need to be replenished for several weeks or months into the future. This information is used in the following ways [41]:

(A) To coordinate the replenishment of SKU's coming from the same source

(B) To select transportation modes, carriers, and shipment sizes more cost-efficiently

(C) To schedule shipping and receiving labor

(D) To develop a master production schedule for each SKU

A typical DRP process consists of developing DRP tables for each SKU at each distribution location and then combining those tables in various ways to create information by which we can improve utilization of distribution and production resources. The planning is done in a way that provides the minimum amount of inventory required to meet demand and maintain safety stocks. DRP receives input from the following [25]:

(A) sales forecasts by SKU

(B) customer orders for current and future delivery

(C) available inventory by SKU

(D) outstanding purchase orders by product purchased

(E) modes of transport used and deployment frequencies

(F) safety stock policies by SKU

(G) normal minimum quantity of product to be purchased.

Once all the inputs are received, DRP generates a time based model of resource requirements by carrying out netting, lot-sizing and offsetting. **Table 5.1** shows an example DRP table. The outputs include:

(A) which product is needed, how much, and where and when it is needed

(B) transportation capacity needed by the mode of transport by the stock location

(C) needed space, man power, and equipment capacity by stock location

(D) required inventory investment by stock location and in total

(E) required level of purchases by product and by supply source.

TABLE 5-1. Example DRP Table

	Past	Week							
	Due	1	2	3	4	5	6	7	8
Forecast		40	50	45	50	40	45	40	50
Scheduled Receipt			150						
Projected On Hand	160	120	220	175	125	85	190	150	100
Plnd. Ship. - Rcpt. Date							150		

The DRP concept can successfully be applied to a multi-site construction company where there are many storage locations and the utilization for each must be calculated efficiently on an integrated information structure. The construction company is located in a supply-chain with many participants. In this case, the customer order becomes material issue for construction projects. Sales forecasts become resource use forecast on the construction schedule. The suppliers of various bulk, consumable and prefabricated materials can also be included as a part of this chain. EPC diagram for DRP applied to construction is shown in **Figure 5.10.**

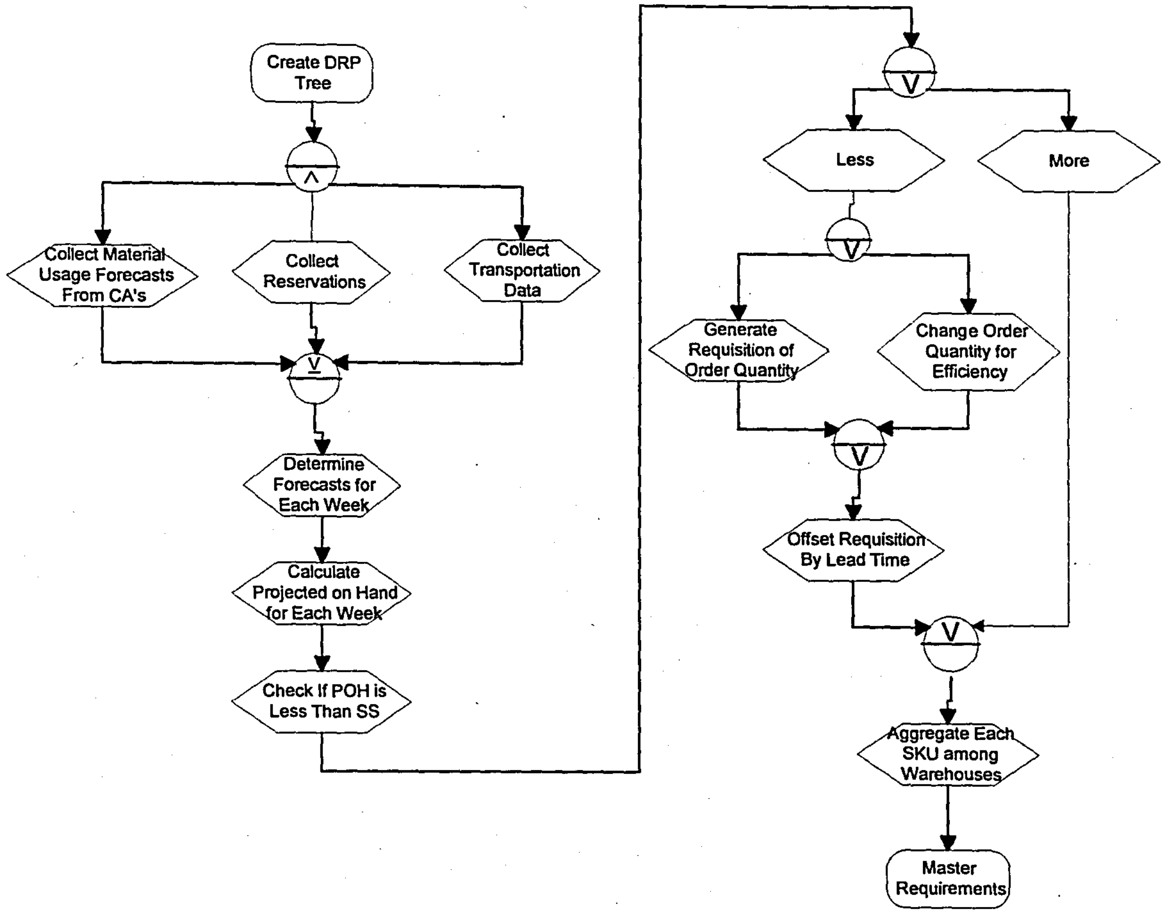


FIGURE 5.10. EPC Diagram for DRP

The entities for DRP are the tables for each SKU and the DRP tree representing the relationships between them. **Figure 5.11** shows the ERD and **Figure 5.12** shows the PCD for DRP implementation. The structure in this framework is as follows: The DRP tables are updated weekly according to the project progress. The safety stock, minimum order quantity and the maximum order quantities are defined under MATERIAL entity. The transportation, purchasing lead times are calculated using previous experience and the agreement with the supplier and included in the materials data. The CONTROL ACCOUNT(CA) entity type is the super-type for the SCHEDULE ACTIVITY which holds the early-late start-finish dates and estimated start-finish dates calculated using a CPM project scheduling software. If there are more than one warehouse on a site with each having the same material, the forecasting is done on a single SKU. MATERIAL-CA ASSIGNMENT relation shows the forecasted or the actual material use for each activity. The status of each material in transportation can also be tracked in the integrated database system. The RESERVATION relation between SKU and CA determines materials at the warehouse or in transit, allocated for specific use in an activity. The sum of all material needs for the activities that will start at the specific week determines the forecasts of the week.

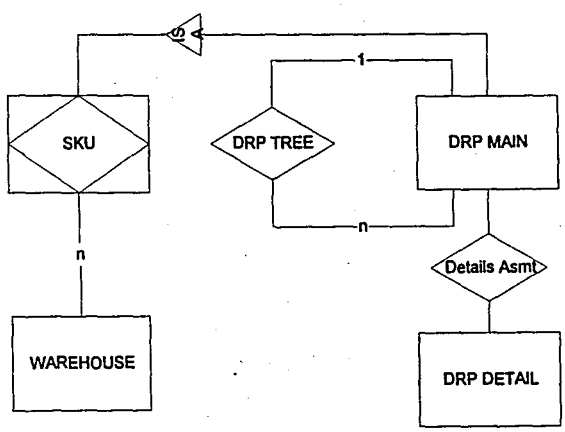


FIGURE 5.11. ERD For DRP Implementation

Balance on hand (BOH) at each week is checked for projected inventories if it exceeds safety stock. If replenishment is needed, it is planned to be received for that week, so lead time number of periods prior to the period of need. The procedure is repeated for each week, using the previous periods projected balance on hand as the starting point for the period.

The planned orders for an SKU, aggregated across all warehouses stocking that item, become the gross requirement that must be met each week.

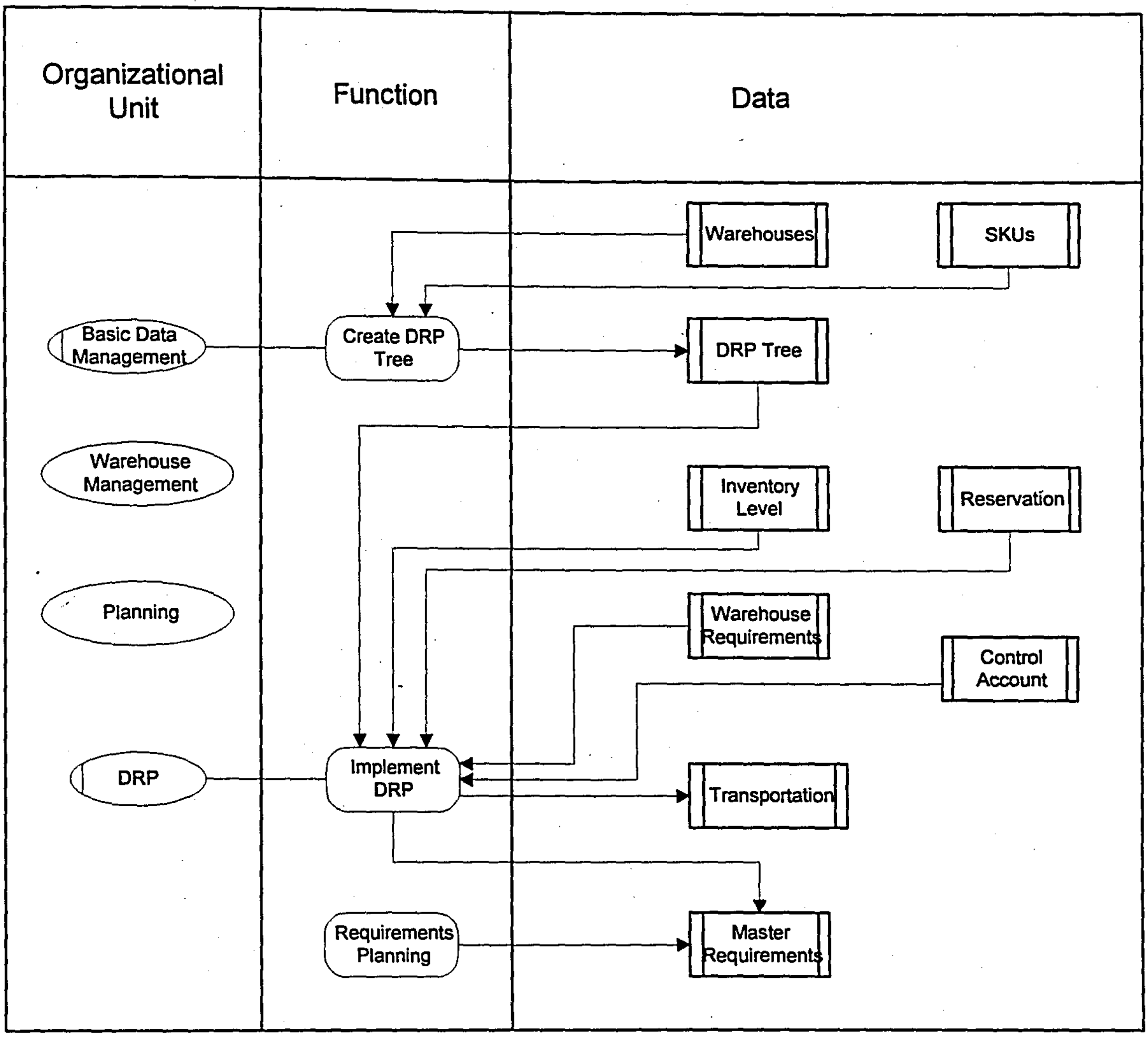


FIGURE 5.12. PCD For DRP Implementation

5.5.2 Design Specification

DRP functions are generally batch processing, where requirements are updated weekly according to the project schedules, actual consumption, and delays. User interface is important for visual representation of DRP tree. Weekly updates can be transmitted via modem among project participants.

5.6 Warehouse and Site Materials Management

5.6.1 Requirements Definition

Although warehouse management and site material management are distinct functions, they are combined under one heading since they are highly interrelated. Together, they cover all the functions from receiving, storage and protection, inventory management, materials handling, quality inspection to field materials control. **Figure 5.13** shows the function tree for site-warehouse materials management.

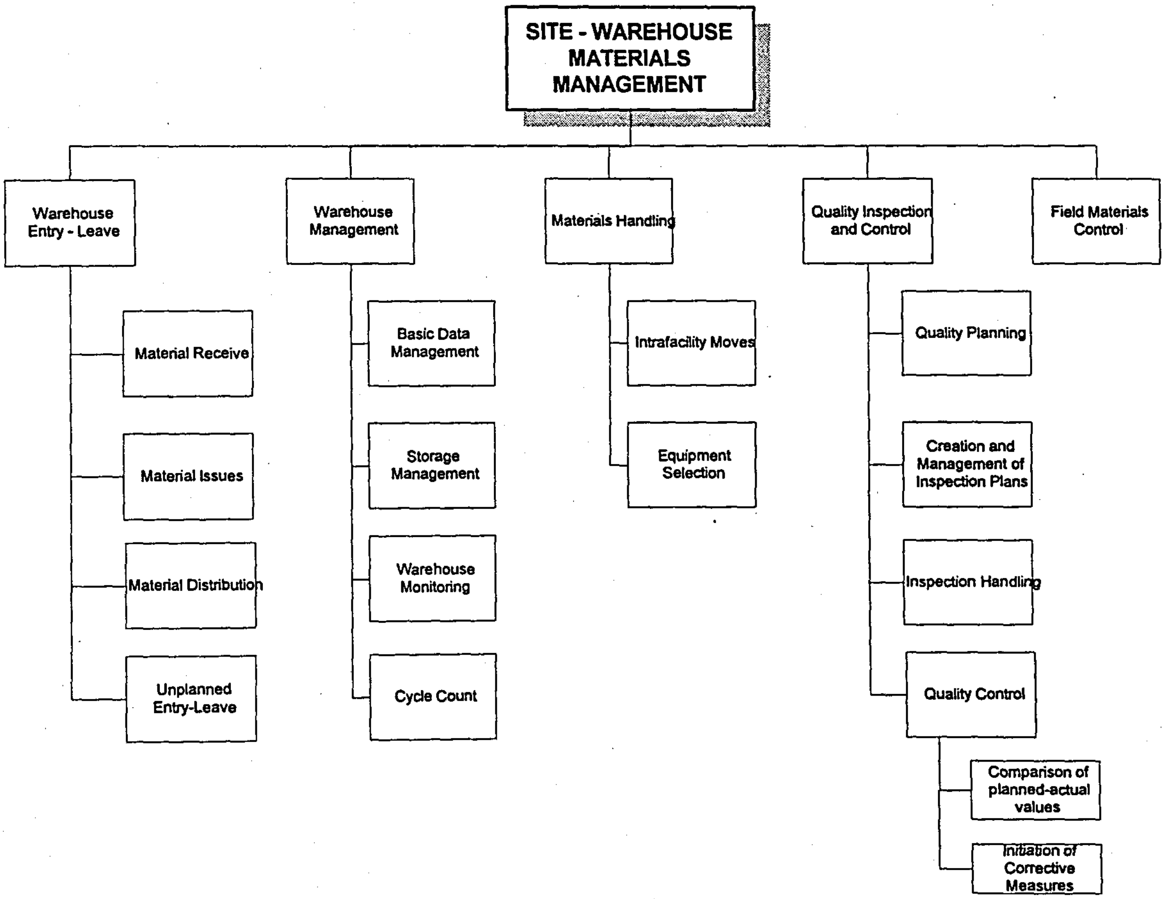


FIGURE 5.13. Function Tree For Site - Warehouse Materials Management

The system allows use of bar-coding for material and equipment tracking. Bar-coding serves as an integrating tool within site materials management. A bar code is a selfcontained message with information encoded in the widths of bars and spaces in a printed pattern. The use of bar-code labels assigns each material a single code number, which helps tracking the material easily. Considerable amount of labor and time is saved

A typically large industrial construction project has a number of distribution centers that receive, inspect, store, and issue equipment, materials, consumables, spare parts, and other items that can be controlled through the use of bar code technology.

Figure 5.14 and Figure 5.15 show the PCD and ERD diagrams for site-warehouse materials management respectively. Actual construction plan is integrated into the system to ensure material flow is consistent with the schedule. The CONTROL ACCOUNT explained in basic data management is the core item for storing and retrieving information on the site. The CONTROL ACCOUNT which is a subtype of WBS keeps track of the status (actual-estimated start-end dates, etc.) of an activity. It is linked to the SCHEDULE ACTIVITY which holds the schedule (predecessor-successor) data. Materials are assigned to the control account with the relationship MATERIAL-C.ACCOUNT ASMT entity. This relationship holds the amount of assigned materials and the properties of the material. Similar relations hold between CONTROL ACCOUNT and EMPLOYEE, EQUIPMENT. Each control account can have many tasks, smallest defined units of work.

WAREHOUSE entity holds the general attributes for the warehouse. Warehouse entity aggregates other types of storage locations such as laydown areas and sheds. WAREHOUSE entity has 1:n relationship with SITE LOCATION entity as each site can have more than one warehouse. Each material is stored under stock-keeping units (SKUs). This convention will allow the implementation of DRP. SKU entity type holds each type of material in a specific warehouse on project basis. INVENTORY LEVEL entity is a subtype of SKU which keeps the amount of inventory for specific lengths and widths of materials. This is especially useful in storing prefabricated materials, pipes and steel structures. Stock-in data are taken from information accompanying delivery or recorded manually or by devices such as bar-code readers. INVENTORY ADDITION relationship between SKU and RECEIVING SLIP ITEM creates the link between purchased material and the inventory. Delivered quantities are counted upon receiving to compare purchasing with received amounts. Correspondingly, stock-out data are registered by preparing either a paper or electronic withdrawal document and represented by MATERIAL LEAVE relation between SKU and MATERIAL.

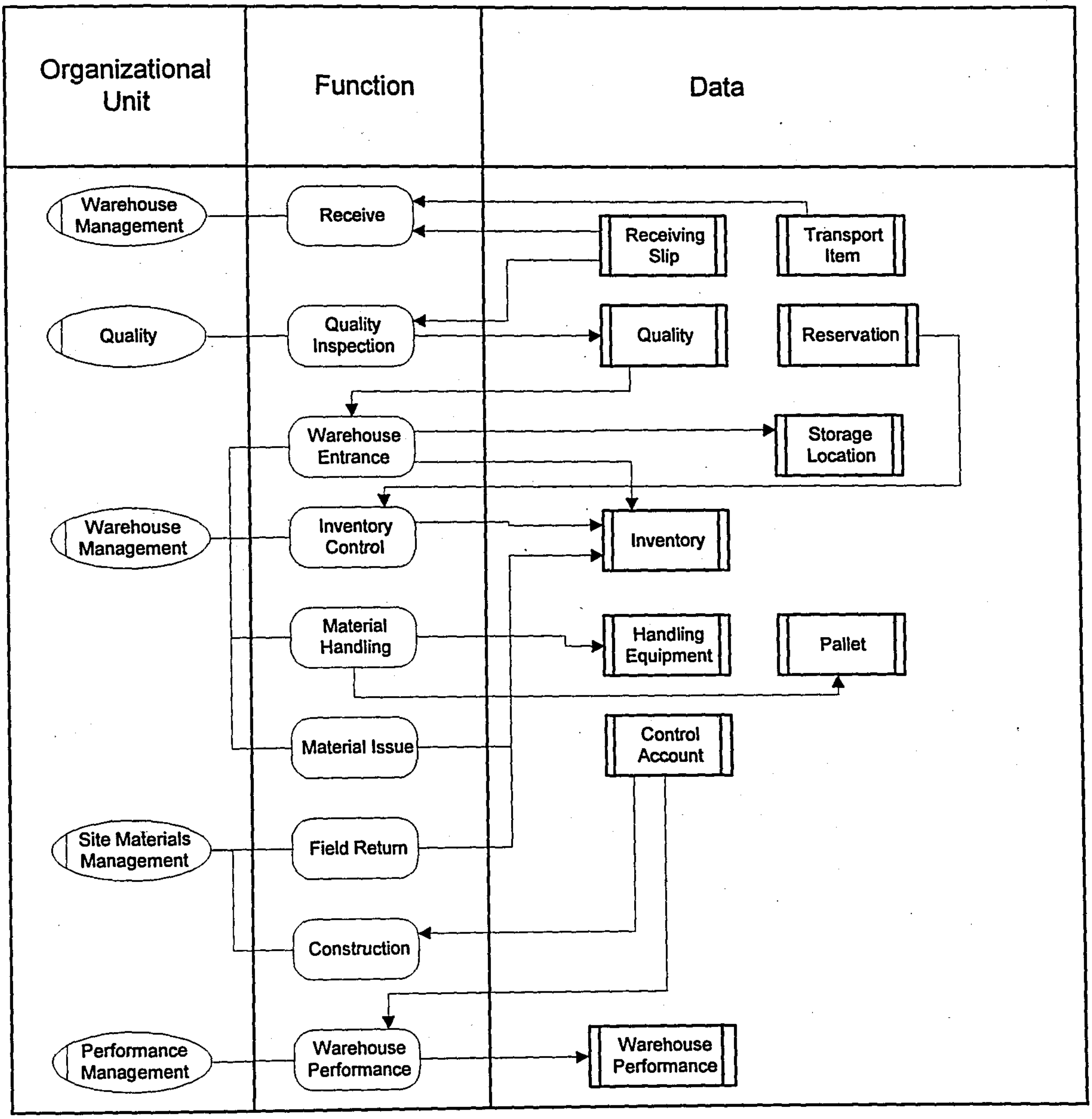


FIGURE 5.14. PCD For Site - Warehouse Materials Management

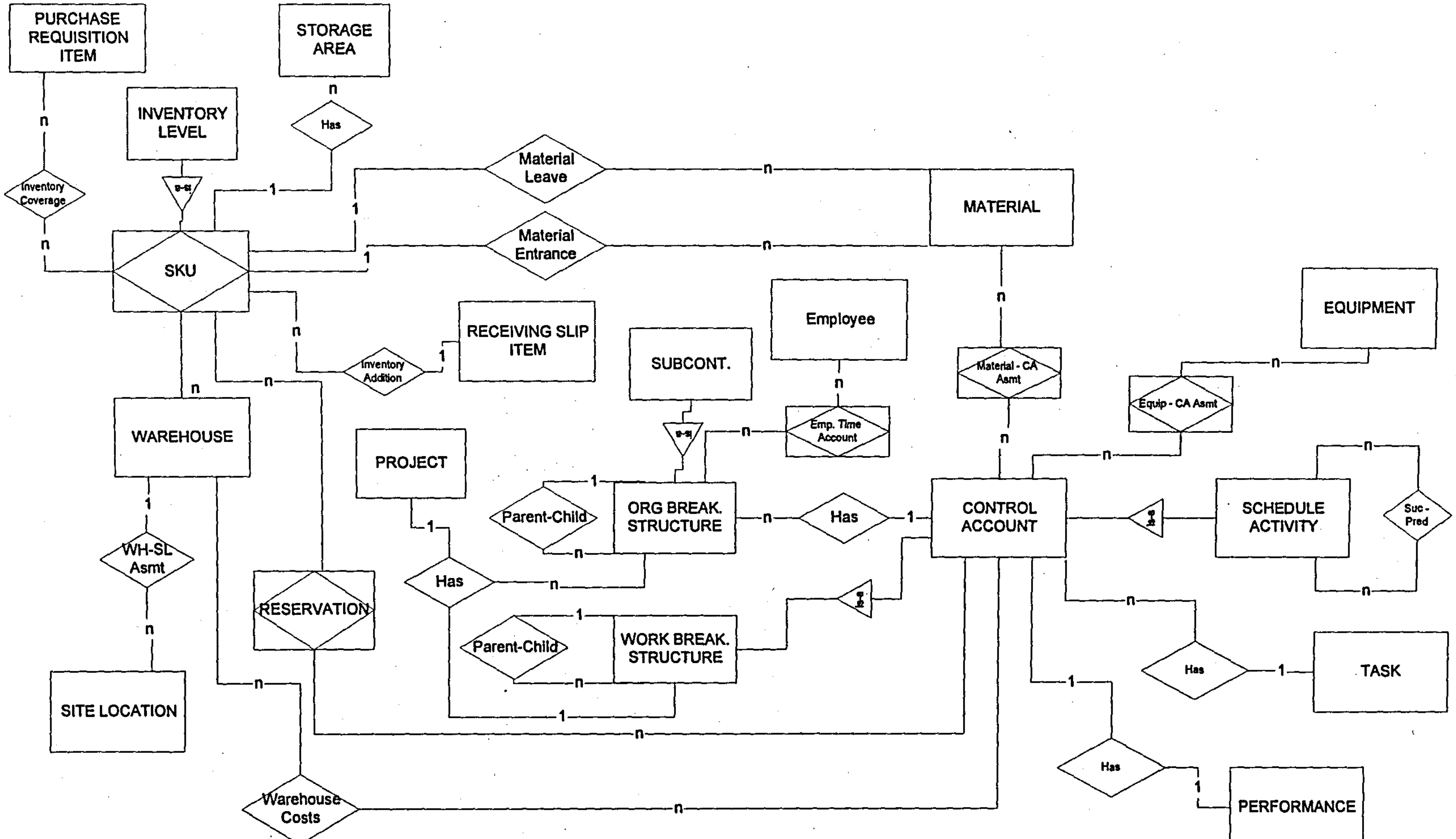


FIGURE 5.15. ERD For Site - Warehouse Materials Management

RESERVATION entity type, introduced under purchasing, keeps material reservation on a control account basis. The reservation can be done during purchasing, or after the material has arrived at the warehouse. Movements of items within the warehouse is represented by STOCK MOVEMENT entity type.

Periodic inventory cycle-counts may be necessary for specified criteria, such as article number, storage location, ABC category, and current inventory level.

Each craft or subcontractor may have its own store for storing their bulk or unique materials. These materials are issued from a warehouse in the site. Materials in the stores are not further counted; instead they are accepted as used materials in the integrated system.

Figure 5.16 shows the EPC diagram for entry of received material. Similar diagrams may be developed for equipment entry and material issue.

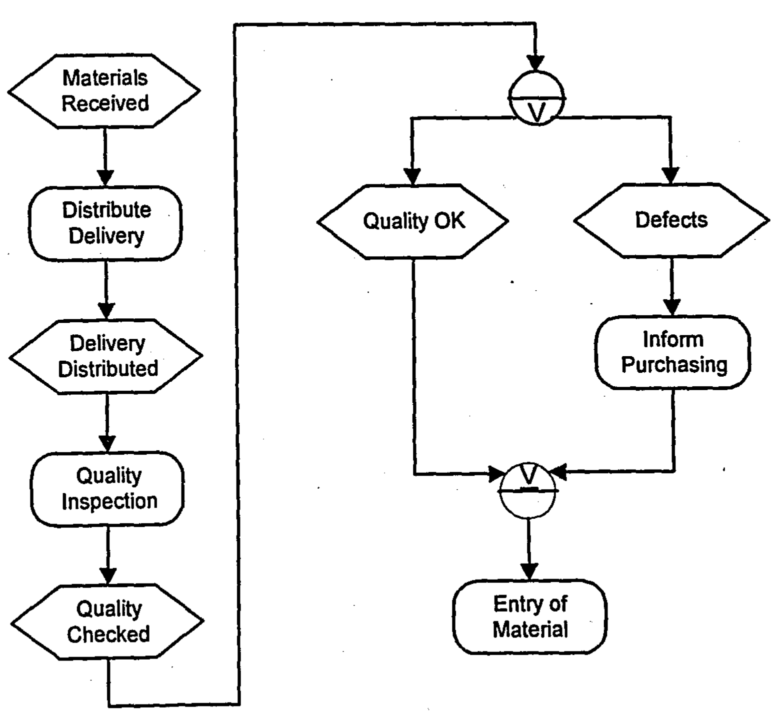


FIGURE 5.16. EPC For Stock-In of Materials

Materials handling might be necessary in the warehouse or on the site. On congested sites such as that for tunnel projects and most high-rise city building projects, material handling problems occur because of the linear nature of construction. So representations for materials handling is further elaborated as a separate diagram. **Figure 5.17** shows the ERD for materials handling.

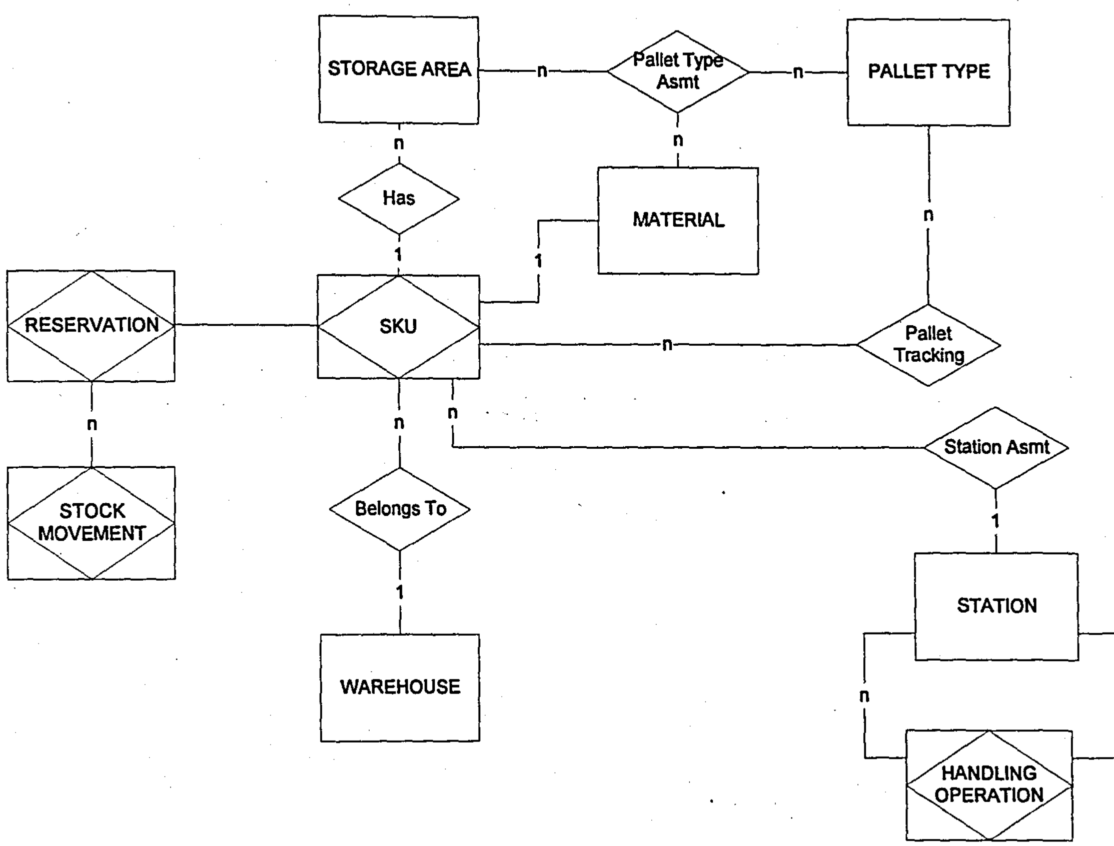


FIGURE 5.17. ERD For Materials Handling

HANDLING OPERATION relationship holds the type and properties of the material handling. STORAGE AREA entity type keeps storage capacity, and storage characteristics (e.g. high protection area, laydown area, shed) related to the storage area. It has relationships with SKU and PALLET TYPE. The material assigned to a warehouse is checked for compliance with the status of the storage area. The volume that materials will occupy can be calculated from the material properties, and it can be seen if it fits in that area. The entity type PALLET TYPE is introduced to manage different pallet types. PALLET TYPE ASSIGNMENT assigns specific pallet type to specific storage areas.

Quality is a significant competitive factor, and in many industrial enterprises it is the third cost element after personnel and material costs. Quality assurance is divided into quality planning, quality inspection and quality control. If quality inspection procedures are performed before physical stock-in and stock-out functions, a distinction can be made between an inventory level within the warehouse and an inventory level within the inspection area. Measures should assure that purchase material, equipment, and services, conform to the procurement documents.

Organizations for site personnel has more complex structure. Organization structure is developed based on the type of contract and execution strategies. There may be many subcontractors in a single project as well many crews.

5.6.2 Design Specification

A comprehensive implementation of site and warehouse management system has barriers because it is hard to convince people at site to enter data. The screen forms and reports should be as user friendly as possible. Most of the functions are interactive including warehouse entry and issue, quality inspection.

By definition, projects are temporary, so developing an expensive network structure between temporary site facilities may seem unnecessary. However it is well worth the cost if the project is medium to high cost. Fiber optics underground network cables between site office buildings and storage areas permit real time update of the integrated database.

The relational database tables for site and warehouse management are shown in **Figure B.4.**

5.7 Human Resource Logistics

5.7.1 Requirements Definition

In an enterprise, the functions of human resource logistics are concerned with retaining and developing human resources. It is possible to divide the human resources functions into basic data management, personnel accounting, and personnel planning as shown in the function tree in **Figure 5.18.**

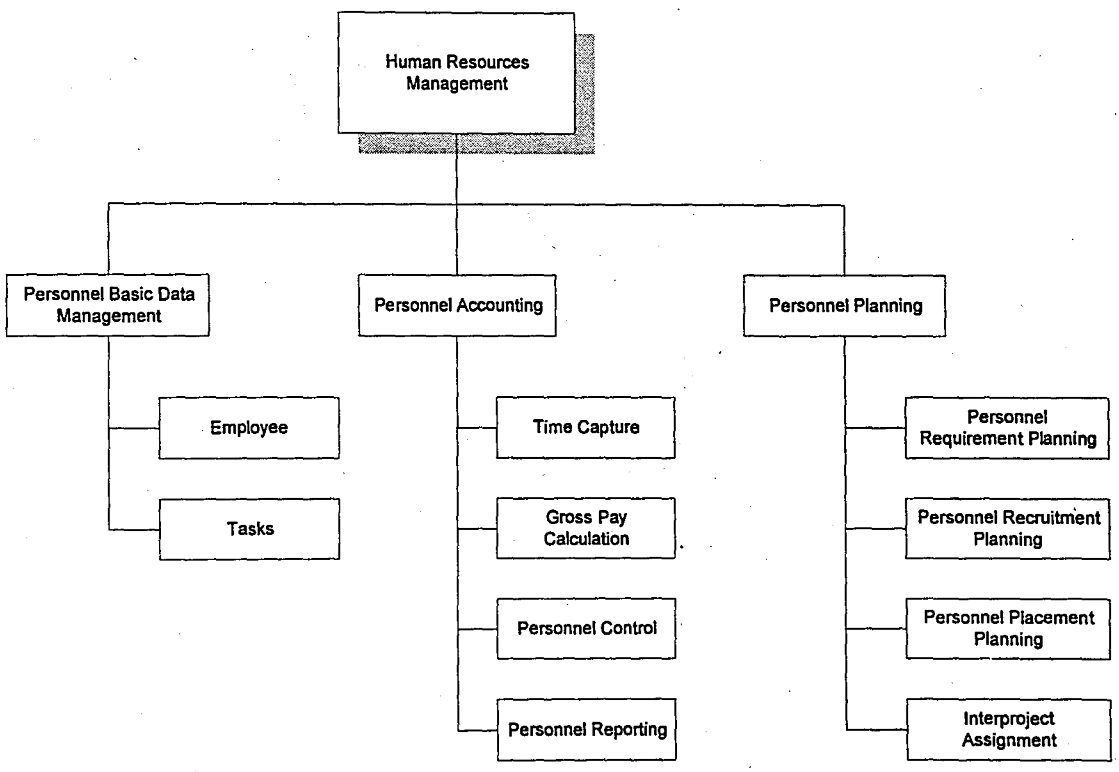


FIGURE 5.18. Function Tree For Human Resources Management

The ERD diagram for human resources is shown in **Figure 5.19**. EMPLOYEE entity type establishes the core basic data. It can be used to generate and manage hirings, dismissals and reassignments. It is also the basis for privilege, and information collection related concerns. JOBS, which exist as a result of the organizational structure of the enterprise, are closely related to personnel data. The organizational structure of the enterprise is formed on the basis of the jobs. An employee is a job holder in OBS shown with JOB HOLDER relation. **Figure 5.20** shows the PCD for human resources management.

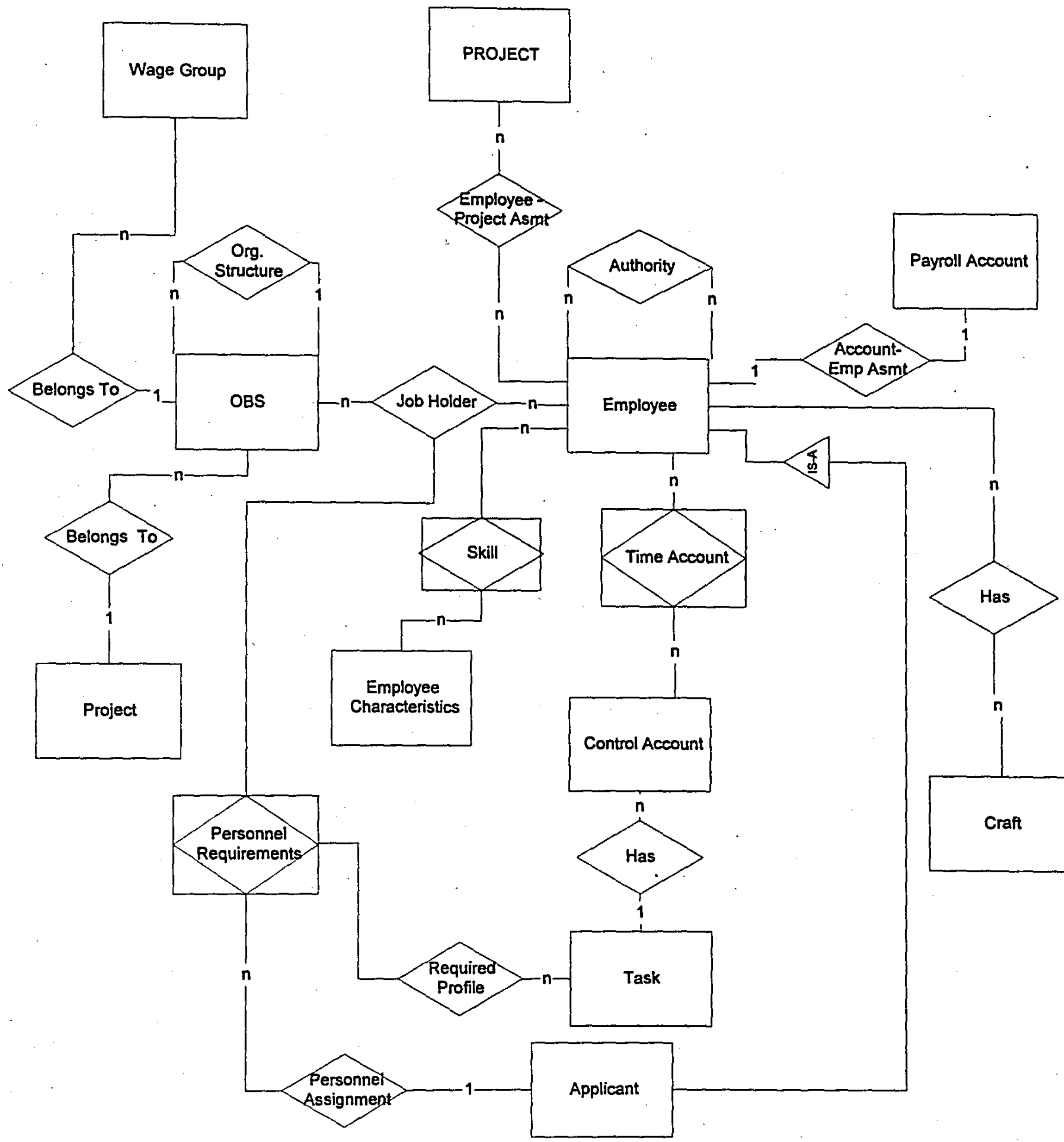


FIGURE 5.19. ERD For Human Resources Management

An organizational breakdown structure is a job plan, i.e., the combination of all jobs that exists in an enterprise. Generally, the organizational structure also specifies the chain of command among the employees. Each project has its own organizational structure that also consists of the subcontractors. The project team is generally assembled from existing members of the organization who are assigned to the project during its duration and who then return to their previous permanent department or position in the organization at project completion [42]. The title and the base compensation of the employee may change after the project. Thus human resources function in project-oriented organizations require flexibility.

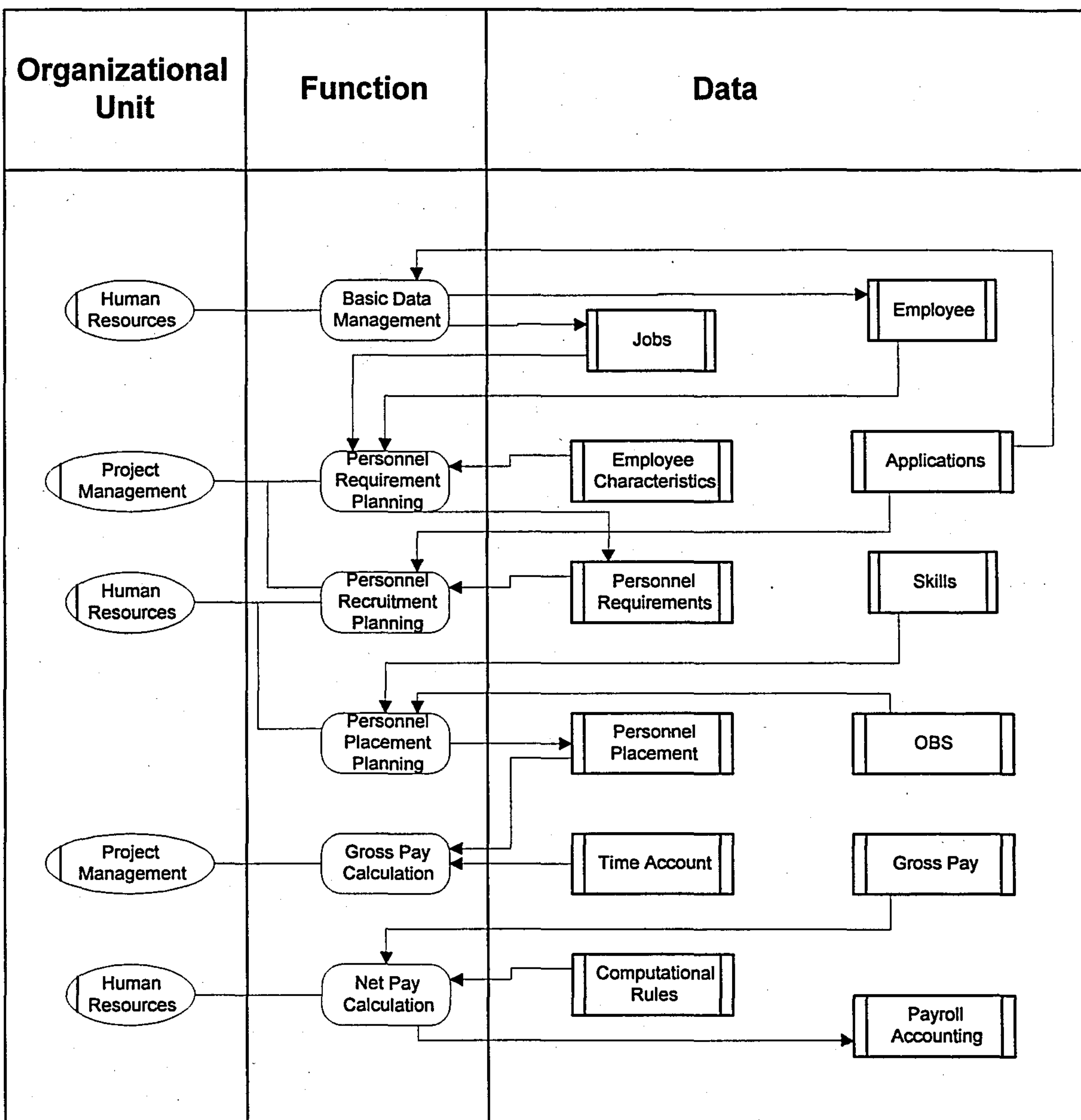


FIGURE 5.20. PCD for Human Resources Management

Human resource accounting establishes the amount of pay calculations for employees. Human resource accounting is divided into gross pay calculation and net pay calculation. Gross pay calculation involves establishing the gross pay on the basis of performance or time related criteria. Net pay calculation calculates the actual payment to the employee from the gross pay. Time related activities of hourly rated project personnel are calculated from TIME ACCOUNT, which holds the worked time for each day in the project. Field labor costs are calculated from this data. The actual costs paid are equal to the hours worked times the wage plus burden rates (social security rates, insurance, other taxes). Field labor hours are minimized by maximizing the effectiveness of the hours worked or "the productivity" of the worker.

Human resource planning deals with planning-related functions, such as human resource recruitment, control and development. Human resources requirements planning determines how many employees or workers with which qualifications will be needed for which projects or jobs. Project managers tend to prefer staff members they have previously worked with. Human resources department prepare and supply the project manager with resumes or other data on those employees for his consideration. Relevant knowledge about the employee such as education, age, physical strength, time management skills is kept under EMPLOYEE CHARACTERISTICS. These characteristics are assigned to each task in a work breakdown structure. EMPLOYEE-PROJECT relationship holds the employee's project work experience with the company.

When project manager is unable to fill the project needs from existing workforce, or a new employee is essential within the company, it is necessary to hire new employees for selected positions. Recruiting activities are performed on the basis of the necessary human resources requirements. While recruiting employees, applicants are entered in employee file. PERSONNEL ASSIGNMENT occurs between PERSONNEL REQUIREMENTS and APPLICANT.

5.7.2 Design Specification

The relational database tables for human resource management are shown in **Figure B.5.** The procedures for human resources and accounting change very often. Different projects have different organization requirements. System should be designed flexible to accommodate all these changes.

Triggers can be defined on the design specification level for formulating access authorizations. These triggers contain access conditions and attach themselves to a transaction when called. This makes it possible to check the authorization of the user placing the query to access the query object.

5.8 Performance Management of Logistic Operations

An operational system should provide information needs for both internal and external requirements [23]. External requirements can be summarized as financial reports for shareholders, lenders, and tax authorities. Internal needs are much more complex and involved. From a logistics perspective, there are two types of internal needs:

(A) a knowledge of the relevant functional costs and performance levels as they are incurred, or shortly thereafter,

(B) attachment of these functional costs and measurements to relevant activities in order to determine each function's contribution to overall logistics system.

An integrated database for construction logistics can successfully handle these needs. The second type of need defined for the performance of the ongoing project can be handled using control accounts. Each functional cost is associated with the control account which is a part of a typical work breakdown structure of a project. Materials and other resources are assigned to related activities in the work breakdown structure, so their performance can be followed on activity basis.

A business is profitable if the value it creates for customers exceed the cost of performing these value-adding activities. To gain competitive advantage over its rivals, a firm must either perform these activities at a lower cost or perform them in a way that lead to differentiation at a premium price(more value). So the key tasks are:

(A) identify these value adding activities;

(B) attach all relevant costs to each activity;

(C) assign these activities and associated costs to each business unit, and

(D) compile meaningful productivity measurements using the appropriate units of activity.

Generally performance management data are regarded as report data, but it is included as independent entities here for keeping historical data. Every project is distinct, and storing the performance of previous projects provide invaluable assistance for future projects. **Figure 5.21** represents the function tree for construction logistics performance management. **Figure 5.22** and **Figure 5.23** show ERD and PCD diagrams for overall logistics performance management respectively.

5.8.1 Project Performance

Cost control is vital in any construction project. Work-packaging model is meant to unify project data, specifically time and cost data, to make the analysis and decision making process easier to perform. Work progress in the work-packaging context is accomplished by variety of methods. One method used for measuring work progress utilizes the units completed in a control account [35]. This method will be used in our context.

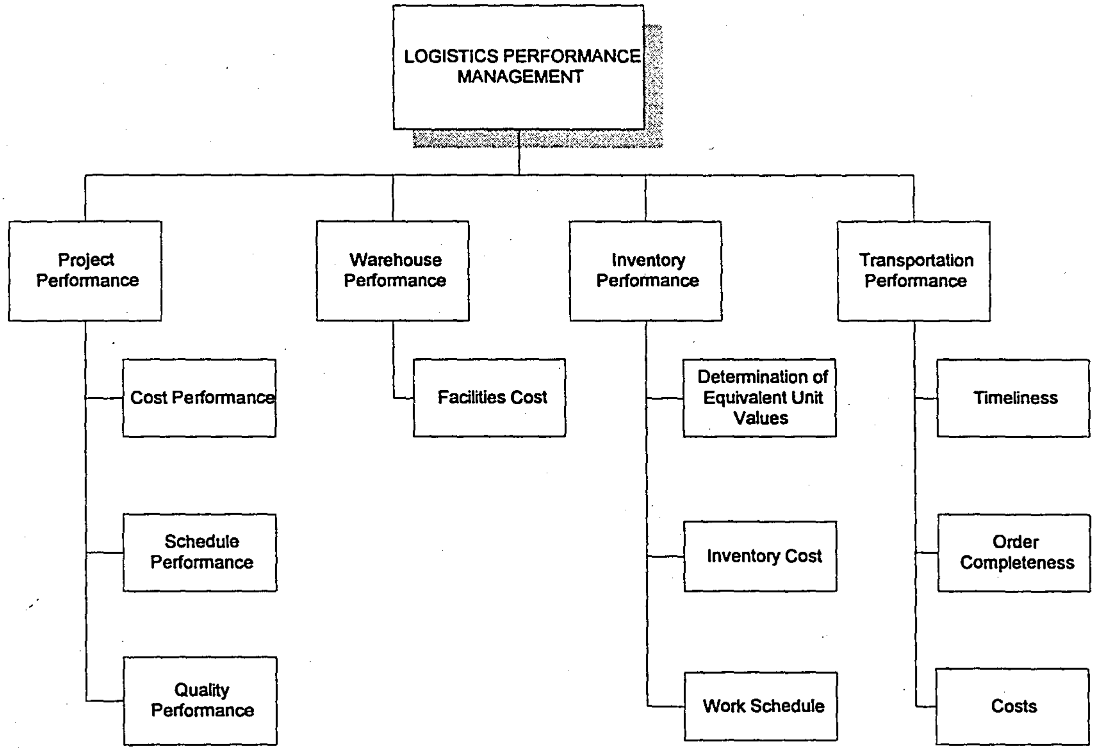


FIGURE 5.21. Function Tree For Performance Management

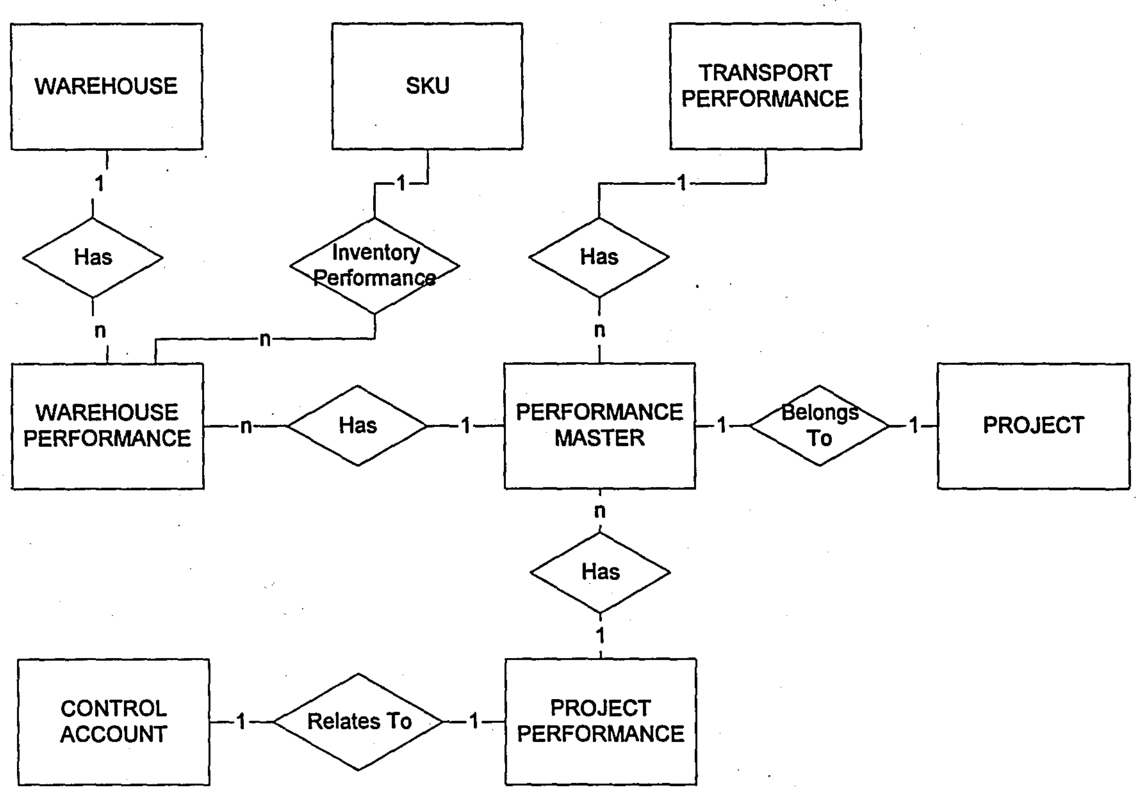


FIGURE 5.22. ERD For Performance Management

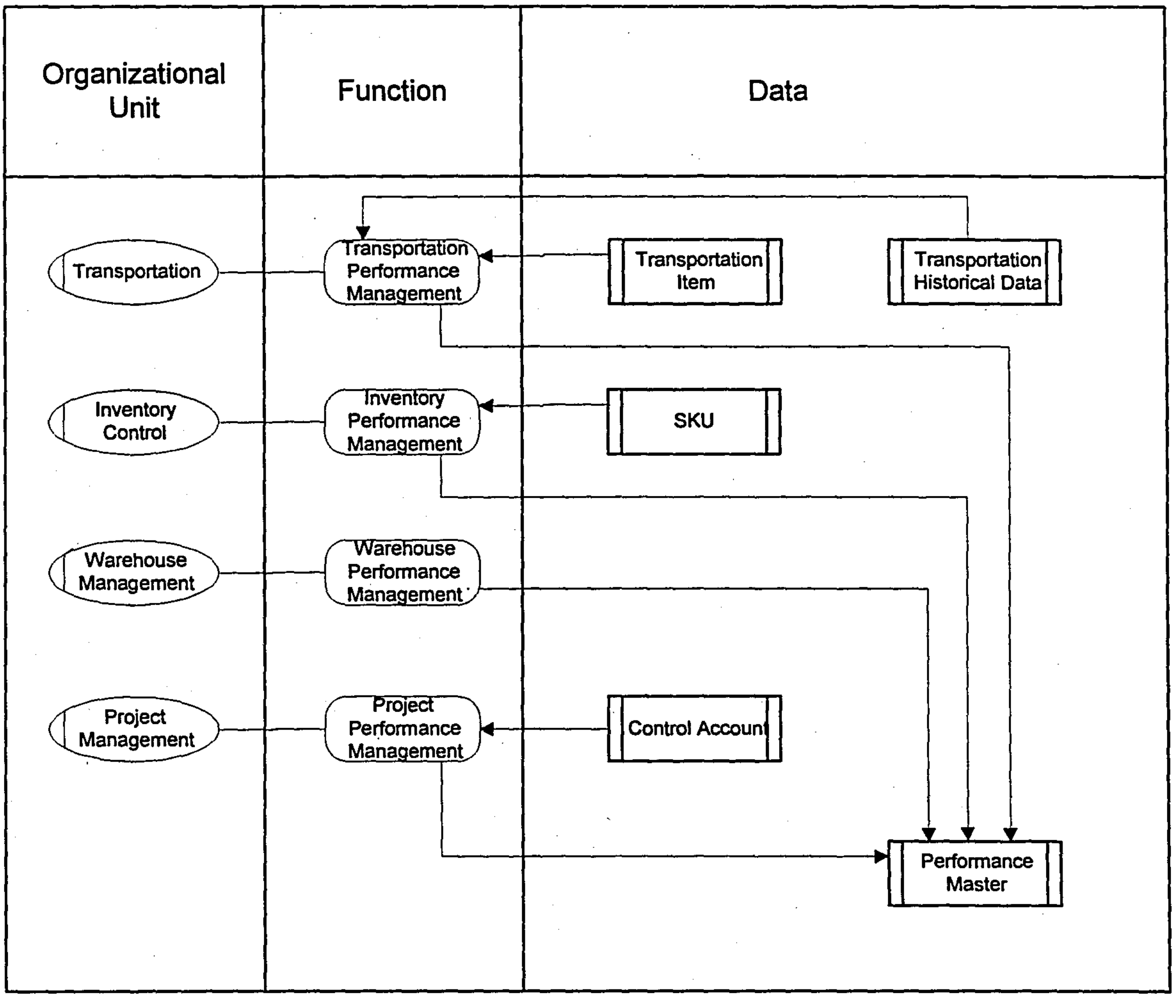


FIGURE 5.23. PCD For Performance Management

There are different cost definitions for cost control in the work packaging model [43-45]. Budgeted cost of work performed (BCWP) is total budgeted cost or work hours of the work completed within a given time period in a specific control account. Budgeted cost of work scheduled (BCWS) is total budgeted cost or work hours of work scheduled to be completed within a given time period in a specific control account. Actual cost of work performed (ACWP) is the total actual cost or work hours incurred in completing a particular work within a given time period in a specific control account. Following formulas are used to calculate the project performance within the system:

$$\%\ \text{complete} = \frac{\text{actual units completed}}{\text{total units budgeted}} \tag{5.1}$$

$$\text{earned value(BCWP)} = \%\ \text{complete x budget for the account (BCWS)} \tag{5.2}$$

The progress in all the control accounts in a given project can be reduced to earned money or work hours by:

$$\text{overall project \% complete} = \frac{\sum_{\text{accounts}} \text{BCWP}}{\sum_{\text{accounts}} \text{BCWS}} \tag{5.3}$$

Control account performance is computed using two indices, a schedule performance index (SPI) and a cost performance index (CPI). These indices are calculated using following formulas:

$$\text{SPI} = \frac{\text{BCWP}}{\text{BCWS}} \tag{5.4}$$

$$\text{CPI} = \frac{\text{BCWP}}{\text{ACWP}} \tag{5.5}$$

5.8.2 Warehouse Performance

For company operated warehouses, all fixed costs are assigned to storage activities (office administration, building depreciation or rent, utilities, supervisory labor etc.) Variable costs (direct labor, materials handling equipment depreciation or rent, fuel, maintenance, etc.) are assigned to handling activities. Warehouse performance is also associated with the timeliness of orders.

Storage and warehouse handling activities can be used to quantify and evaluate a variety of productivity related measurements, including:

(A) calculating facilities costs per area;

(B) comparing company owned facilities' costs and productivity with public warehouse vendors.

6. IMPLEMENTATION OF PROTOTYPE CONSTRUCTION LOGISTICS SYSTEM

Implementation description of the system defined previously can show great differences depending on the structure and size of the company. **Figure 6.1** shows EPC diagram for transferring the design specifications of the system to implementation in this study. This diagram will be explained later in detail.

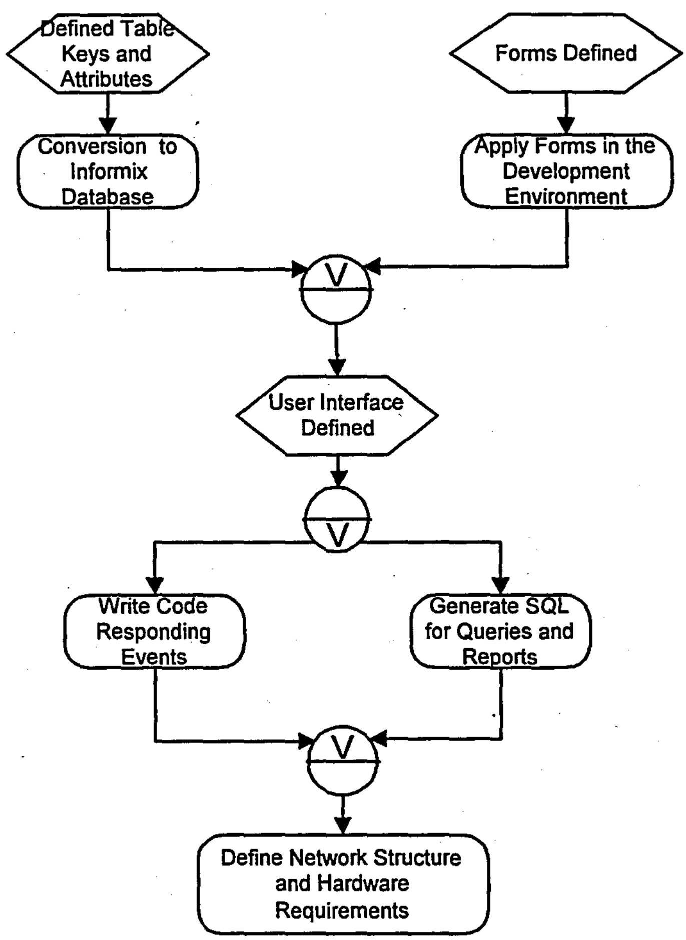


FIGURE 6.1. EPC Diagram for Conversion from Design to Implementation

6.1 DBMS and Development Tools Employed

For the implementation of the prototype integrated construction logistics system in this study, a relational database management system was chosen. Although object-oriented databases are emerging as standards for integrated engineering information systems, relational databases are more mature with extensively defined and implemented tools in the market. Logistic functions are more routine and transactional, so reliable, well defined tools are necessary. Tools are emerging to integrate the relational data into integrated services working on object oriented architectures such as CORBA standard architecture (Common Object Request Broker Architecture). Entity-relationship modeling which takes mostly relational model into account is used as a base for some object oriented modeling systems. This makes it easier for the system to integrate with object oriented architectures.

The database management system is the software that handles all access to the database [38]. The main functions for a DBMS are the following:

(A) Data definition : The DBMS must be able to accept data definitions and convert them to appropriate object form. It should include a language processor to convert various data definition languages (DDL) to internal format. For example, it should be possible to generate a materials table and its attributes, then load it with values by using a specific DDL.

(B) Data manipulation : The DBMS must be able to handle requests from users to retrieve, update, or delete existing data in the database, or to add new data to the database.

(C) Data security and integrity: The DBMS must monitor user requests and reject any attempts to violate the security and integrity rules.

(D) Data recovery and concurrency : Recovery is restoring the database to a state that is known to be correct after some failure has rendered the current state incorrect. The DBMS should allow many transactions to access the same data at the same time, known as concurrency. Unless controls are placed on the use of data, concurrency can lead to a variety of negative effects. Programs can read obsolete data, or modifications can be lost even though they were apparently completed. To prevent errors of this kind, database server imposes a system of locks.

(E) Data dictionary : The data dictionary can be regarded as a database on its own. The dictionary contains "data about the data" (metadata). All of the various schemas and mappings will physically be stored in the dictionary.

(F) Performance : The DBMS should perform all of the functions as efficiently as possible.

From a high-level point of view, a database system can be regarded as having a very simple two-part structure, consisting of a server and a set of clients. With centralized processing, the central computer controls data management, processing functions and input and output editing. The clients are where the users interact with an interface. In a client/server architecture, a central server manages the central data, which are used by many applications. **Figure 6.2** shows the structure of a client/server system. Client/server architectures are supported by new hardware developments and gaining advantage over traditional mainframes.

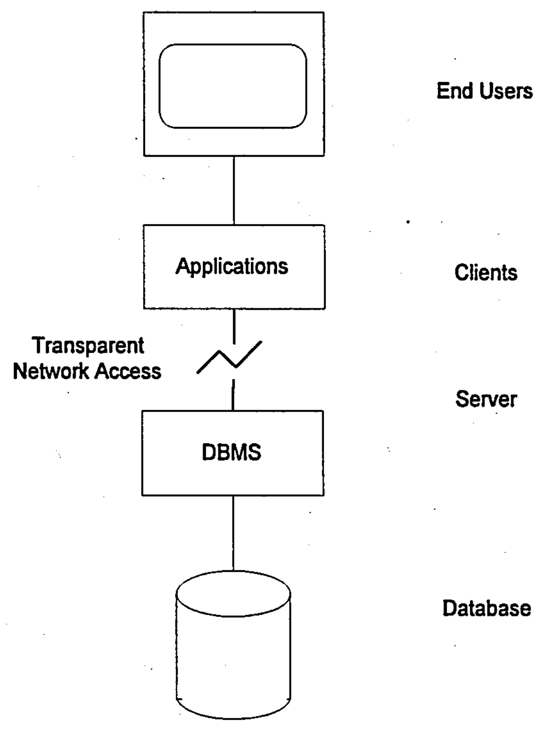


FIGURE 6.2. Client - Server Architecture

A single client might need to access different server machines, as enterprises do not collect their whole data on one single machine, but spread across many distinct machines. A distributed database system is a database system that allows the client to be able to access many servers simultaneously, as if they were a single server, regardless of the actual physical state of affairs.

SQL is the ANSI standard language for dealing with relational systems, currently supported by most commercial database products. It is the language that is used to direct all operations on the database. SQL is composed of statements, each of which begins with one or two keywords that specify a function. SQL statements are Data Definition Language (DDL) and Data Manipulation Language (DML) statements.

The database management system (DBMS) used in this study is Informix Online Relational Database Management System. Informix Databases servers use Dynamic Scalable Architecture (DSA) to take full advantage of parallel computing. DSA maximizes performance through its ability to optimize the processing power of the hardware. They are based on a client-server architecture. Informix Online Workgroup server supports applications using images or voice, as well as Web-based applications to use the database as a central storage service. Informix Workgroup Servers have user-friendly tools for database administration. Graphical interface exists for database installation, setup, configuration, and administration. Integrated client/server and desktop connectivity and distributed enterprise application support are among some other properties. Informix servers have ANSI SQL-92 entry level conformance. **Figure 6.3** shows the Informix Workgroup Server(WS) general structure.

Many applications may be used in an integrated logistics system, and their interactions should be well defined. The tools used for developing the prototype integrated construction logistics application in this study are Visual Basic provided by Microsoft and New-Era Development Environment provided by Informix.

Microsoft Visual Basic is a rapid application development tool for Microsoft Windows operating system. It integrates event driven programming, simplified graphical

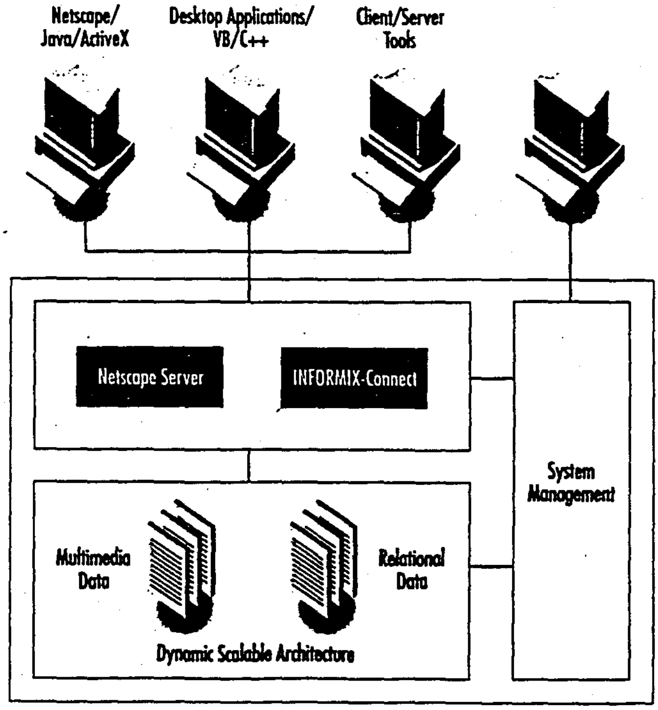


FIGURE 6.3. INFORMIX WS General Structure

user interface (GUI) development, and component based programming. Its ease of use and access to database systems using Open Database Connectivity (ODBC) drivers allow for quick and efficient development. ODBC drivers permit accessing to different database management system in a standardized format. Thus the software codes developed for a specific DBMS can be reused for another DBMS.

New Era features a component-based, object oriented architecture with facilities for distributed, partitioned applications, team-oriented and repository development [46]. New Era supplies an object-oriented programming language as well as tools for form painting, code generation, code editing, component browsing and reuse, debugging, and development process management. The language is also a structured programming language, a fourth-generation language allowing rapid programming for database access and reporting. It supports event-driven programming.

6.2 Data View

For implementation of the data view, a new database is developed under Informix and the design descriptions are converted to the physical database. The keys and attributes of tables, which evolved in design specifications, and their types are entered as an MS Excel file. Relational database tables in Informix are formed using a Visual Basic for Applications (VBA) program, which generates the Informix SQL DDL file automatically from that Excel file. **Figure 6.4** shows the tables in the system.

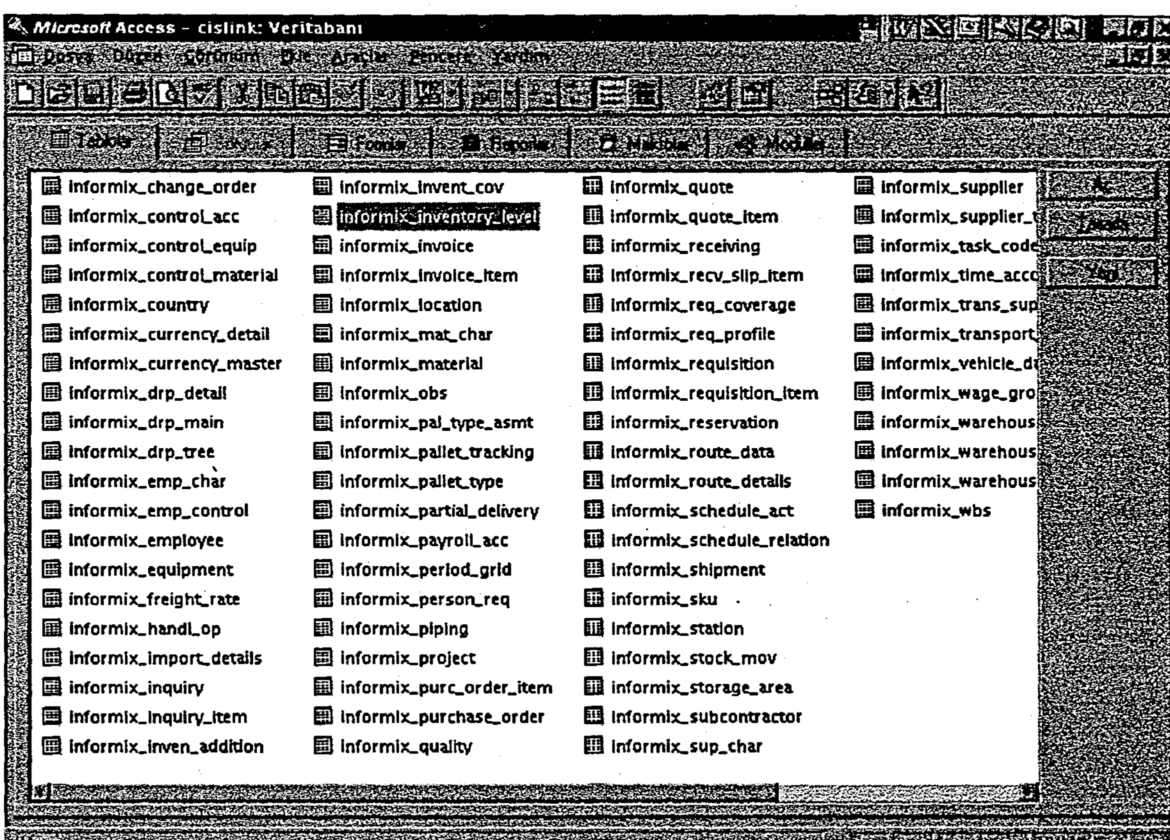


FIGURE 6.4. Relational Tables in the System

6.3 Function View

Forms are developed for the system by aggregating conceptually similar tables. Forms are organized such that each can be opened using a single tree structure. This makes the program user-friendly. There are several interaction elements used in the program, such as text boxes, list boxes, tabs. **Appendix C** shows screen shots from the implemented prototype software.

Security and access control is also important in a multi-user environment. Security involves ensuring that users are allowed to do the things they are trying to do , so it protects the data against unauthorized disclosure, alteration, or destruction. Construction projects frequently involve changes and working simultaneously. Previous versions of the project status may also be referred. So versioning management should also be included.

AutoCAD R13 interface with the database was achieved. This interface allows for relating primitives in the CAD system with the tables in the database. Purchasing, inventory data can be related to any element on the drawing model.

Usually the contents of a report are defined using a statement from a query language. The report layout is defined using special commands or graphical tools which may include specifications of report heading and footing, column names, any totaling or subtotaling and the size of each column. Report results can be converted to MS Excel, or MS Word files. Also charts may be developed for quantitative results, such as inventory levels for SKUs.

6.4 Organization View

The physical network structure is highly dependent on the scale of the site, and the interrelationships among the site, office and the plants. In construction enterprises, distributed nature of the participants, size and disorderliness of the site make it harder to implement a network system. A new network system will be dependent on the size of the office or the site as well as the performance and the cost appreciated. In implementing a network solution for an existing computer system, an assessment should be made of existing computer hardware and software that is used, noting any mission critical operations and resources they depend on.

6.5 A Case Study

The concepts explained so far are applied to a hypothetical construction company which constructs two process plants in the same country. The company has its own steel fabrication plant, but it also purchases some piping material and equipment from other sources. Each process plant has two warehouses, and laydown areas in site. Purchase orders for procured items are generated from home office of the company. Company keeps track of the material levels in the warehouses of the projects in an integrated fashion. Bulk material procurement can be done from external suppliers who in turn can also manufacture or purchase from other suppliers. As it can be seen, the network structure of a construction can be highly complex and be dependent on many factors.

The design, construction, procurement of the process plant take place concurrently. A partnering agreement has been established with the designer who is located in a foreign company. Material and equipment coding for the projects are standardized, and each equipment is tagged with its code.

The complete 3D model of the plants were generated on a plant design system. A screen shot of the design screen is shown in **Figure 6.5**. The complete representations include all the pipes with accurate dimensions, schedules, specs; and other piping elements, detailed to the bolts. Long lead item procurement is handled by the contractor and equipment drawings are received by the designer. All the steel structure is also represented in the model with the plates, excluding the manufacturing details, bolts, and welds. So the complete bill of quantities is represented in the 3D model. The shop drawings and bill of assemblies for steel are generated on a separate software which can take 3D CAD model steel structure as input. Pipe spool drawings are also created on the plant design software to decide on the manufacturing pipe lengths. Staff at the fabrication plant has access to the plant design software, which means that they can extract material lists whenever necessary as the design progresses. The actual status of the construction schedule resides in the database, so the fabrication personnel can make the planning considering the date of erection.

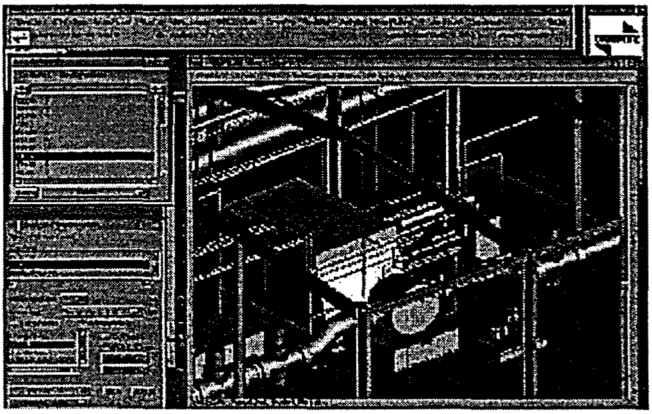


FIGURE 6.5. 3D Plant Design Software Screen Shot

3D CAD data is an integral part of the database, i.e. 3D model simultaneously update the materials database. It is not allowed in the system to generate purchase orders for fabricated materials not available in 3D model.

The DRP structure allows to follow the amount on hand and requirements of distinct warehouses and collect all in a single database to decide on material requirements. **Figure 6.6** shows the distribution in the case study. The warehouses are constructed with other temporary facilities in the site. Once the storage areas are constructed, they are included in the DRP tree. There is an initial high amount of bulk material entry to the site before the start of a process plant construction. There may be unutilized material left during the construction. Also shortage occurs because of material defects, change orders. The purchase orders are transmitted automatically using EDI.

The fabrication of pipe or steel in the plant of the company are directly related to the site requirements, thus to the schedule of the project. The relationships between the contractor and the fabricators of the same firm resembles blanket orders where the customer agree with the supplier to purchase a consistent amount of material for a period of time. The ultimate end result for the integrated system is, a site engineer working on a project can follow the current status of the project, and can query the availability, date of delivery and transportation status of materials required in the schedule directly on the 3D CAD model of the plant, if he has the adequate permission. The bulk and consumable materials are not modeled in the 3D model and requested by site personnel.

There could be numerous different queries and reports generated in the system. Some examples are shown in **Table 6.1. Figure 6.7** shows a purchase order that can be developed by the integrated structure, including data from transportation and supplier. Queries can also be done graphically, e.g. the materials required for the following week in the schedule that are still not in the site warehouse could be highlighted on the 3D model. Each subcontractor is a node on the organizational breakdown structure, so the scope of the subcontractors can be shown on the 3D model also with a single query.

The network structure of the system is shown in **Figure 6.8.** The main office has its own internal local area network (LAN). Frame relay connection connect remote locations (Main office and two sites). Fiber optic cabling is placed between the office buildings and warehouses on each site. This provides faster and integrated network structure on each site.

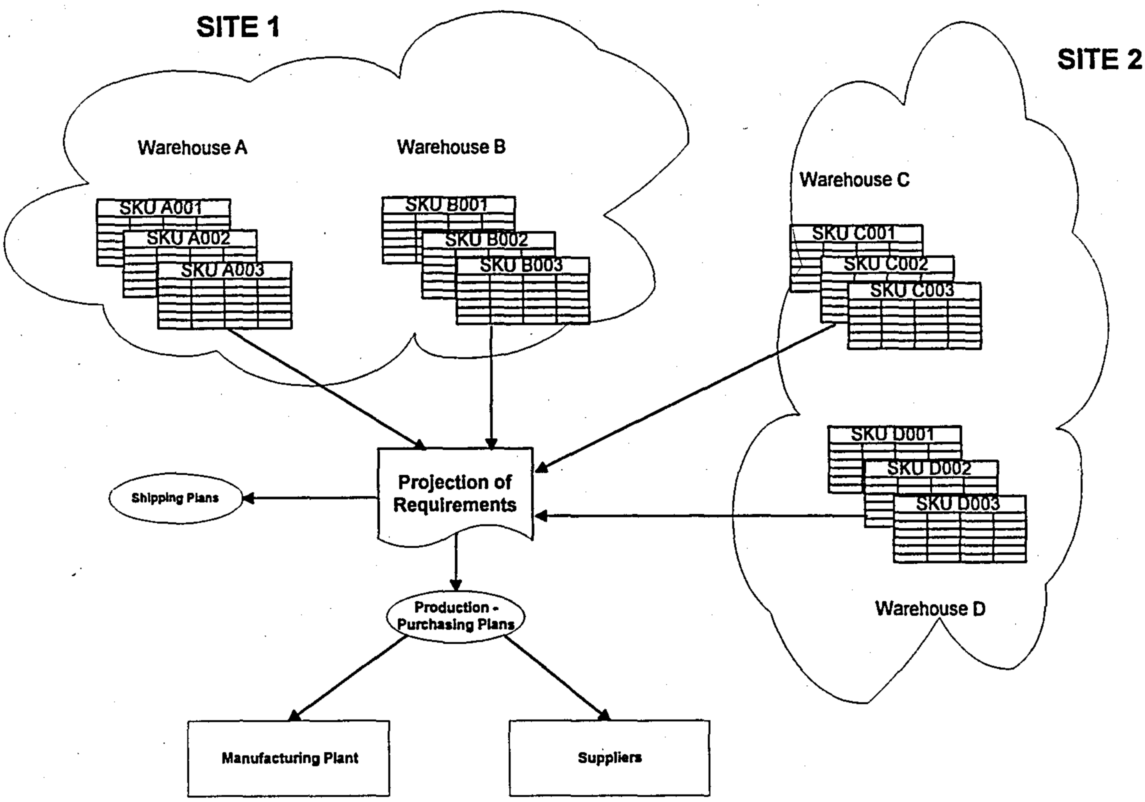


FIGURE 6.6. Distribution in the Case Study

TABLE 6.1 - Example Queries

(a) Warehouse Properties

wh. code	wh. name	location desc.	space capacity
A	Th.Plant #1 WH#1	Bursa Yenikoy	2100
B	Th. Plant #1 WH#2	Bursa Yenikoy	1600
C	Th. Plant #2 WH#1	Yatağan	1500
D	Th. Plant #2 WH#2	Yatağan	600
MAI	Fabrication Plant	Gemlik	2000

(b) Inventory Levels

warehouse code	*A*	*sku code*	*234*		
item no	*quality*	*mat. on hand*	*reserve stock*	*width*	*length*
1	ST 37	12	10	0	5760
2	ST 37	20	10	0	11980

Purchase Order

Purchase Order No.	97101003

Project No.	20
Project Name	Process Plant#1
Project Location	Bursa
Date	23.05.97
Prepared By	Ali Taşçi

Item No.	Quantity	Mat. or Eq. Code	Unit Price	Value
1	10	NIP1	3400	34000
2	25	NIP2	2900	72500
3.	60	PIP1	91000	5460000
Control Account	20510		**Total Value**	$5566500

Transporter Firm Atasoy Transport		
Ship Via Truck	**Weight (kg)** 40	**Volume (m^3)**
Shipping Terms		
Seller hereby accepts and agrees to all terms and conditions, and only those term and conditions contained on the reverse side of this purchase order		
Accepted By	George Deans	
Title	Sales Manager	
Company	PipeTrade	
Date	20.05.97	

Invoice Instructions
Send 2 copies of invoice with original bill of lading.to

Attachments

FIGURE 6.7. A Purchase Order in Case Study

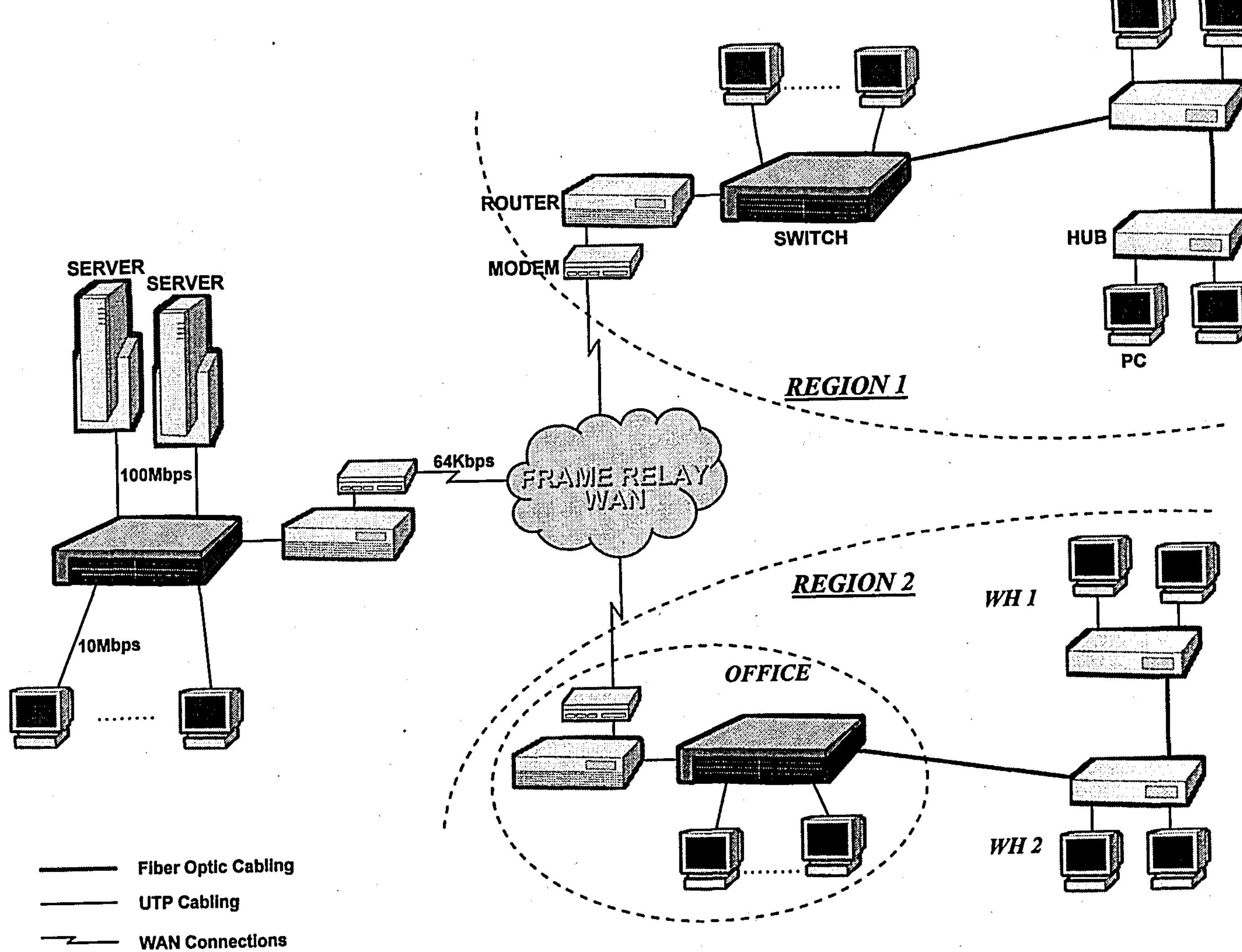


FIGURE 6.8 Network Diagram

7. CONCLUSION

In this study, utilizing emerging technologies and concepts, an integrated construction logistics framework was proposed and a prototype model was implemented. The tools used are ARIS for process modeling, Informix Workgroup Server for database management system, and New Era, Visual Basic for development environment. A case study was prepared for explaining the use of the concepts on a hypothetical project. It is illustrated that an integrated logistics environment is not unattainable.

Greater and efficient IT use in construction industry will reveal schedule reduction, quality improvement in short term and cost reduction in the long term.

This study may be regarded as an initiative research for a broad, rapid-changing area. The future extensions for this study may be a fully object oriented architecture, making use of emerging STEP standards, Industry Foundation Classes. Also the system may be extended to include world-wide-web based integration for project participants.

The implementation of the full system is not complete. Only a small portion was implemented for demonstrative purposes. Many more events, triggers, reports can be prepared.

APPENDIX A

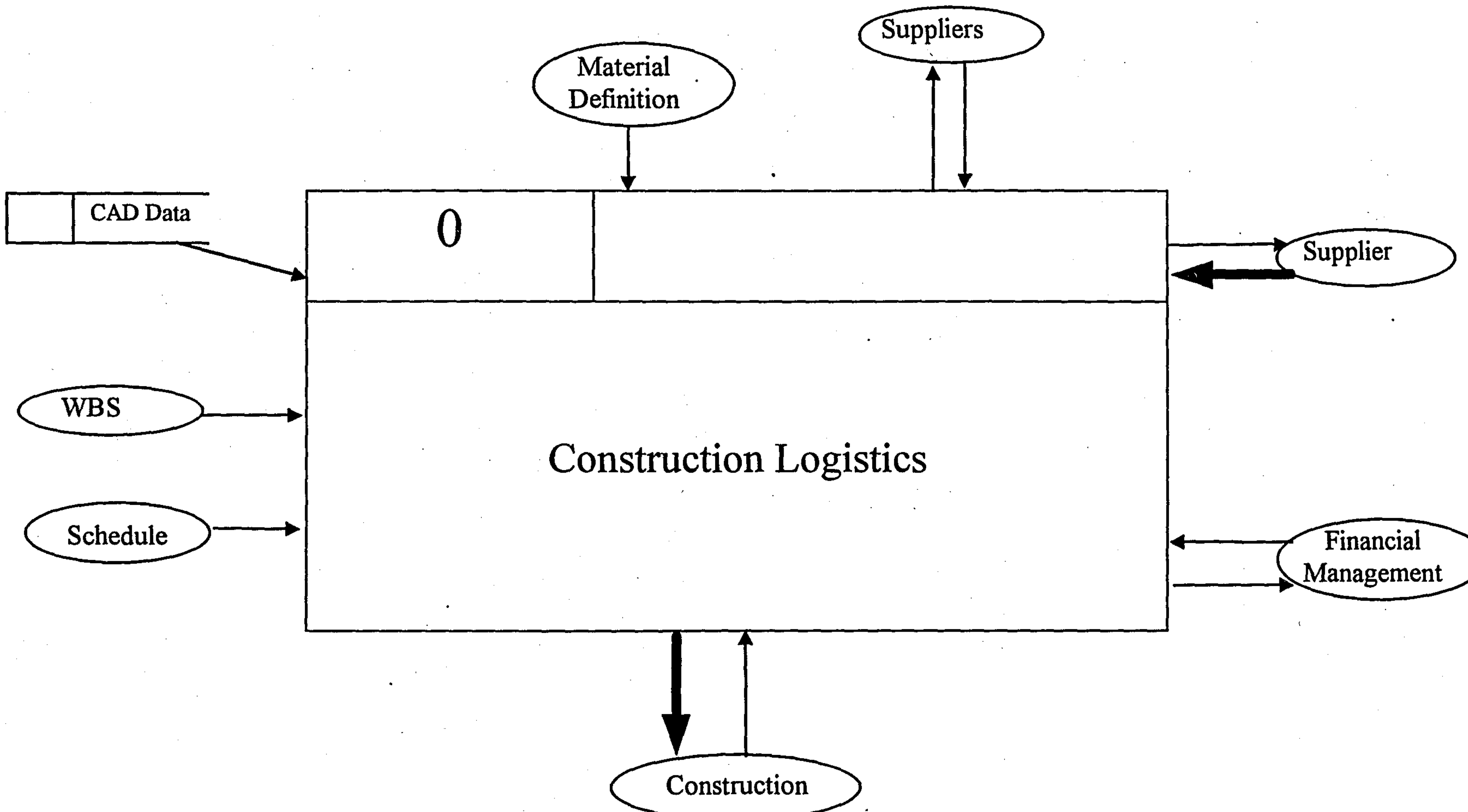


Figure A.1. Level-0 DFD

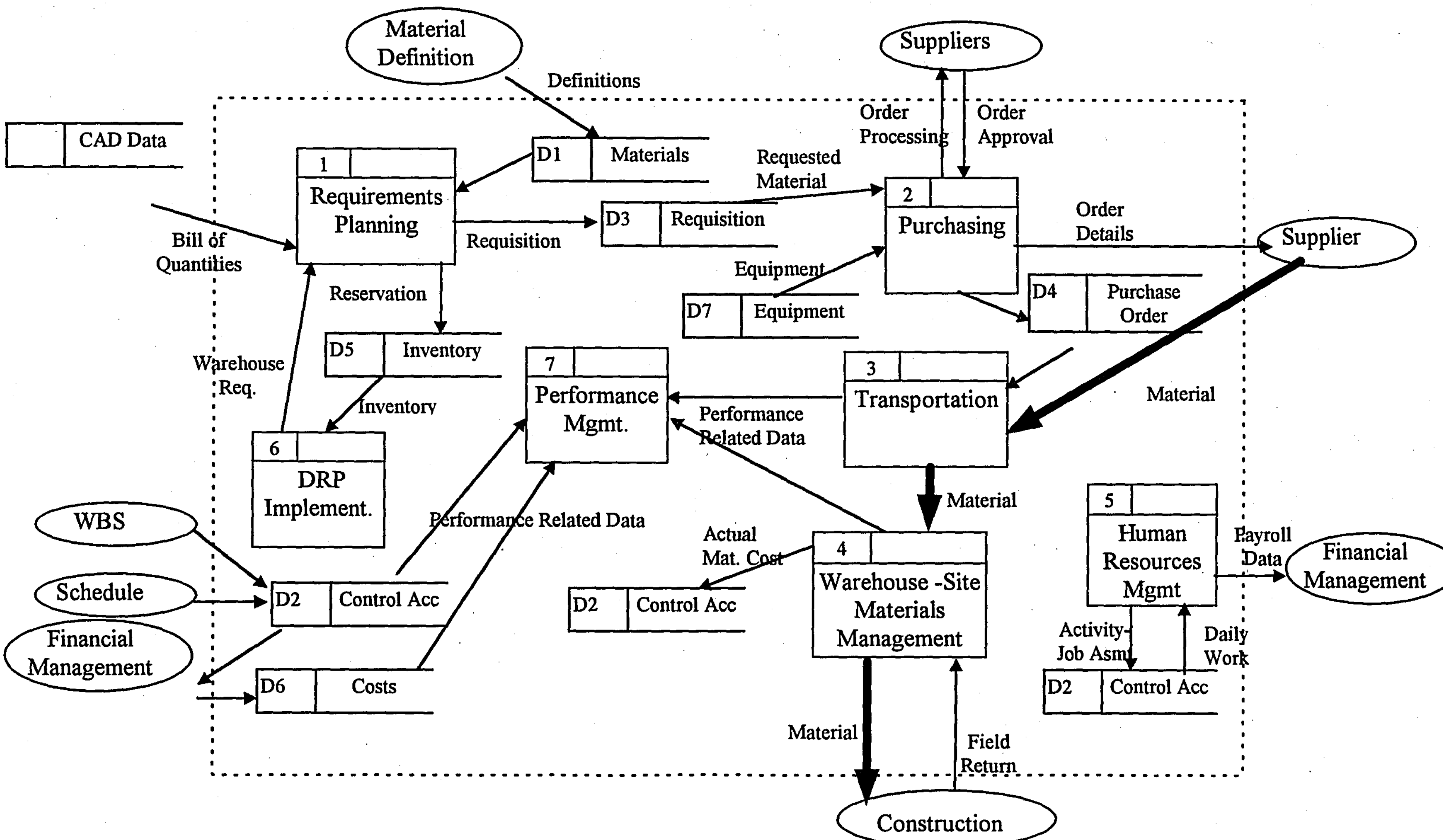


Figure A.2. Level-1 DFD

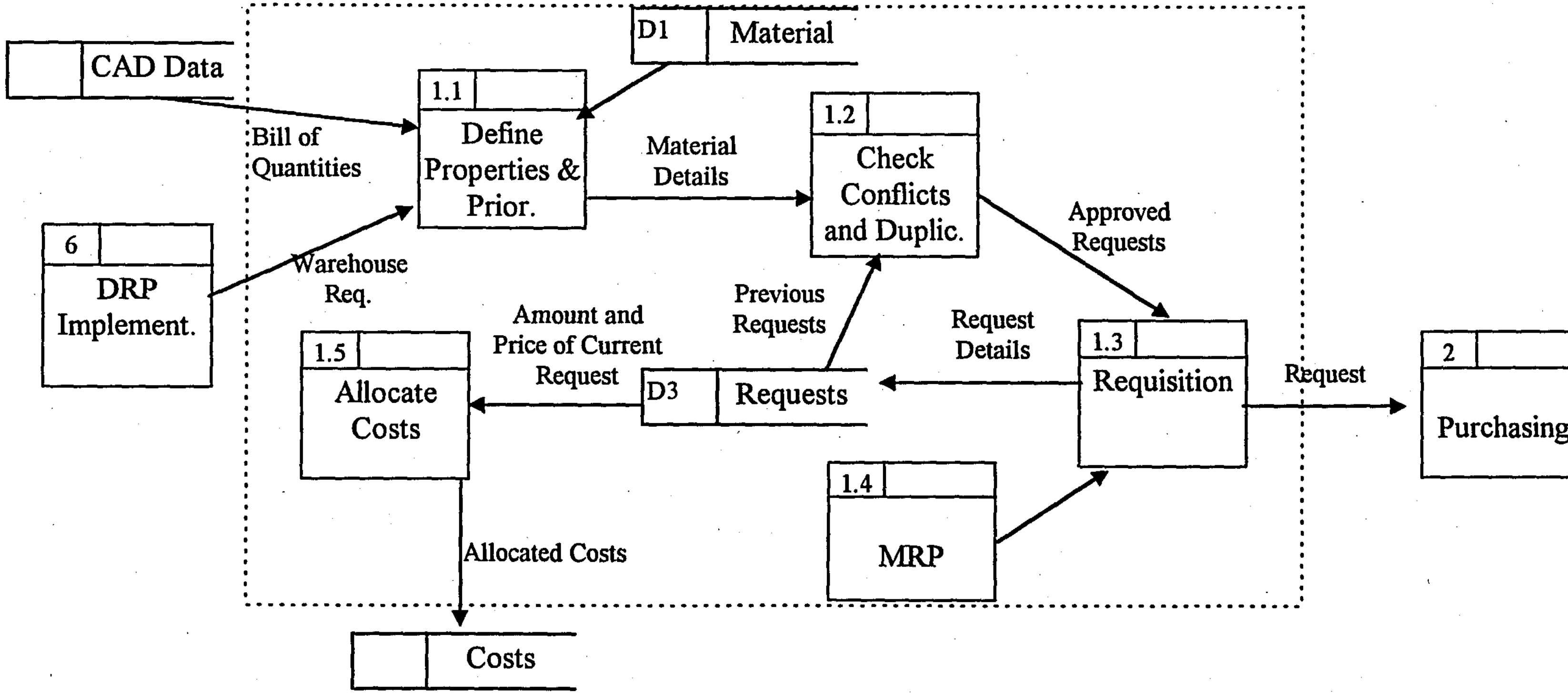


FIGURE A.3. Level-2 DFD of Requirements Planning

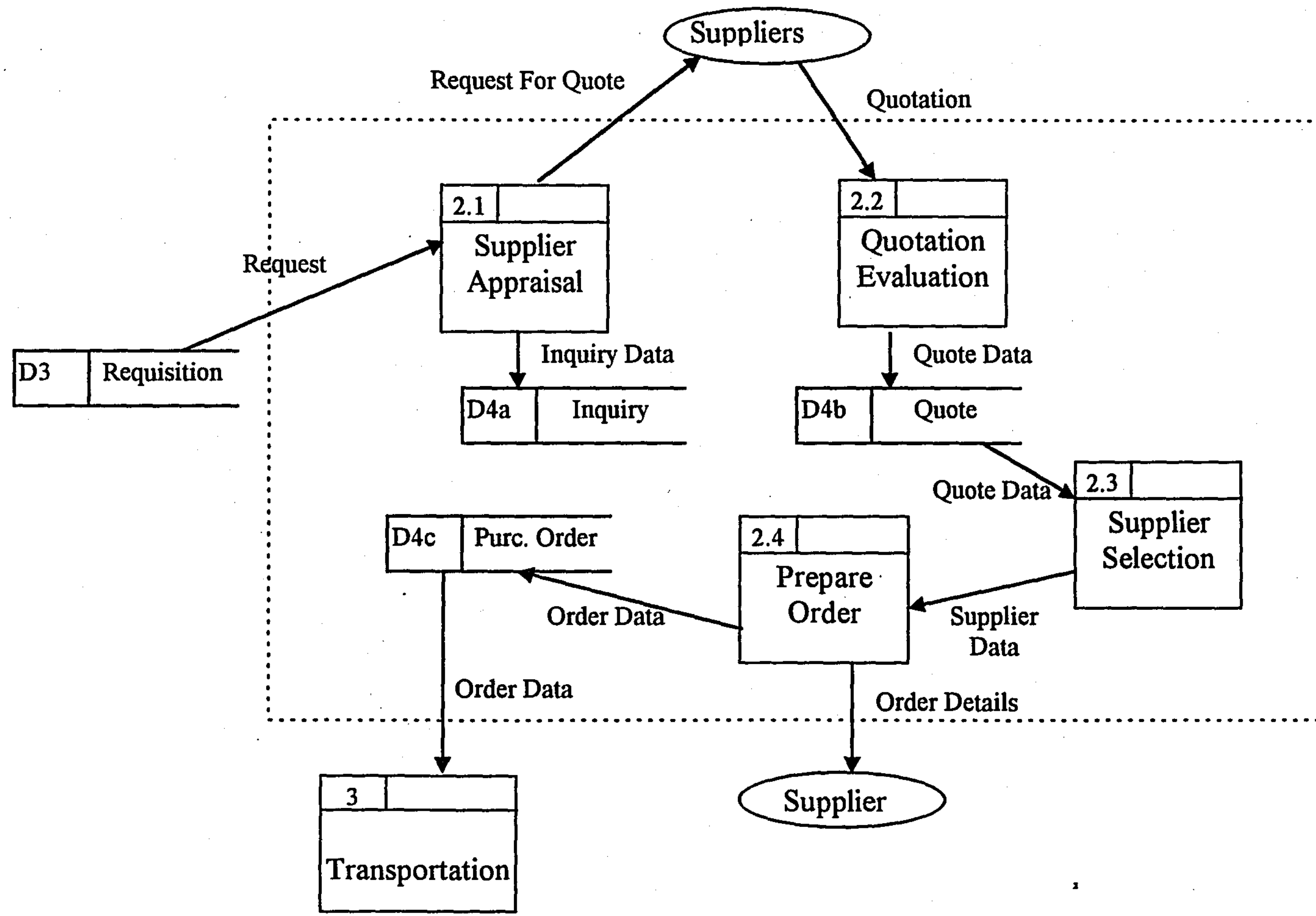


FIGURE A.4. Level-2 DFD of Purchasing

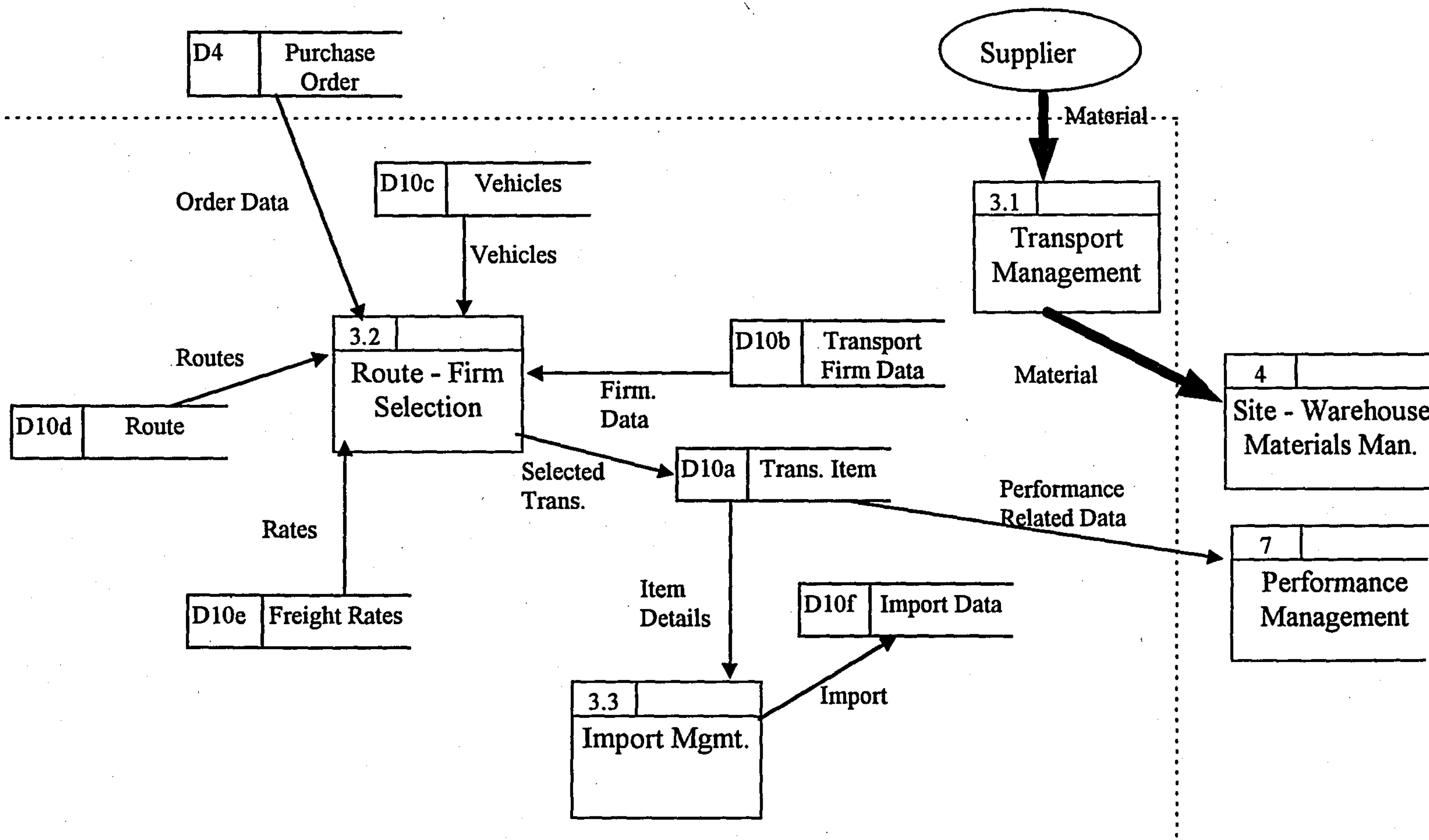


FIGURE A.5. Level-2 DFD of Transportation

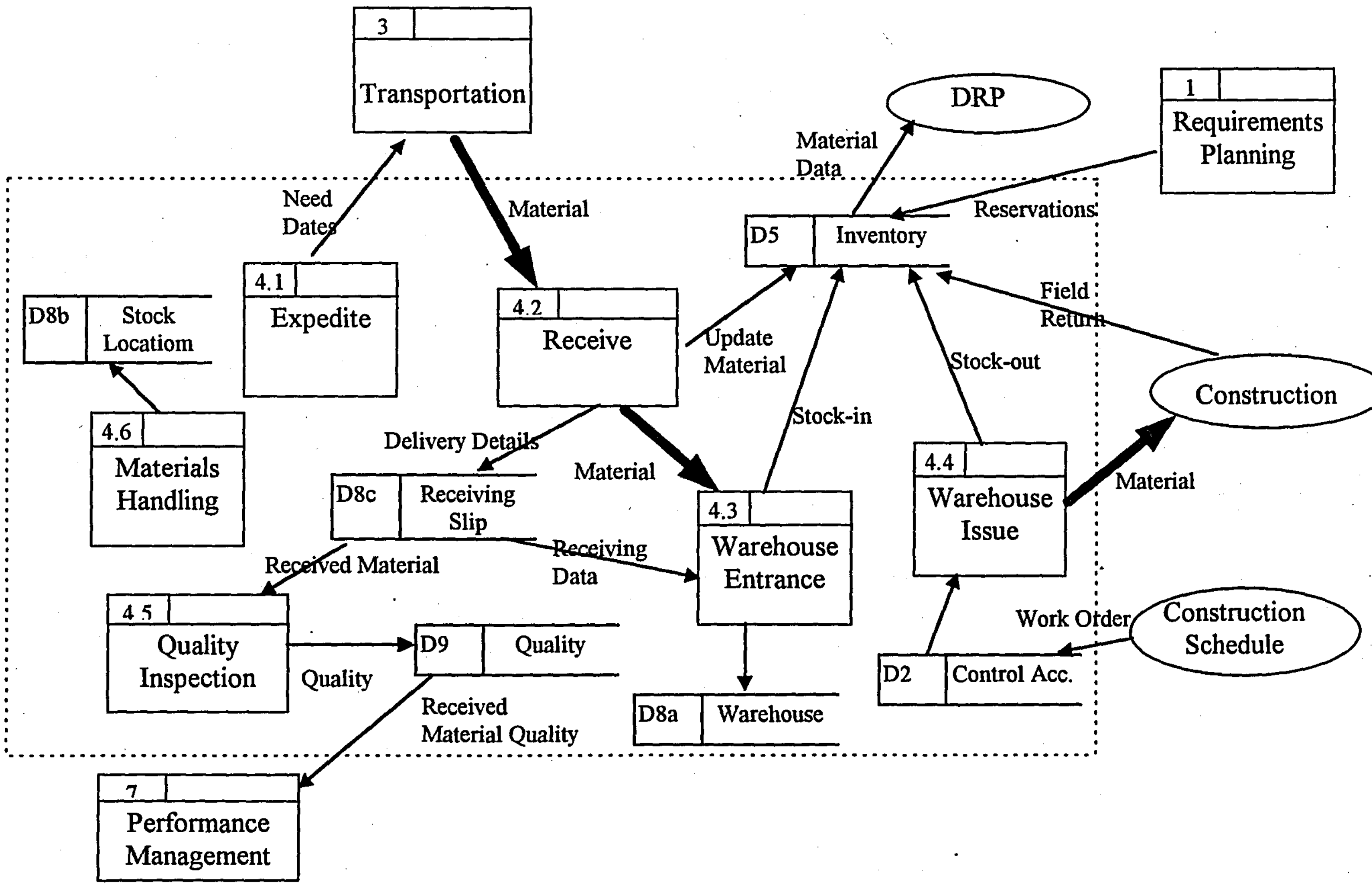


FIGURE A.6. Level-2 DFD of Site- Warehouse Materials Management

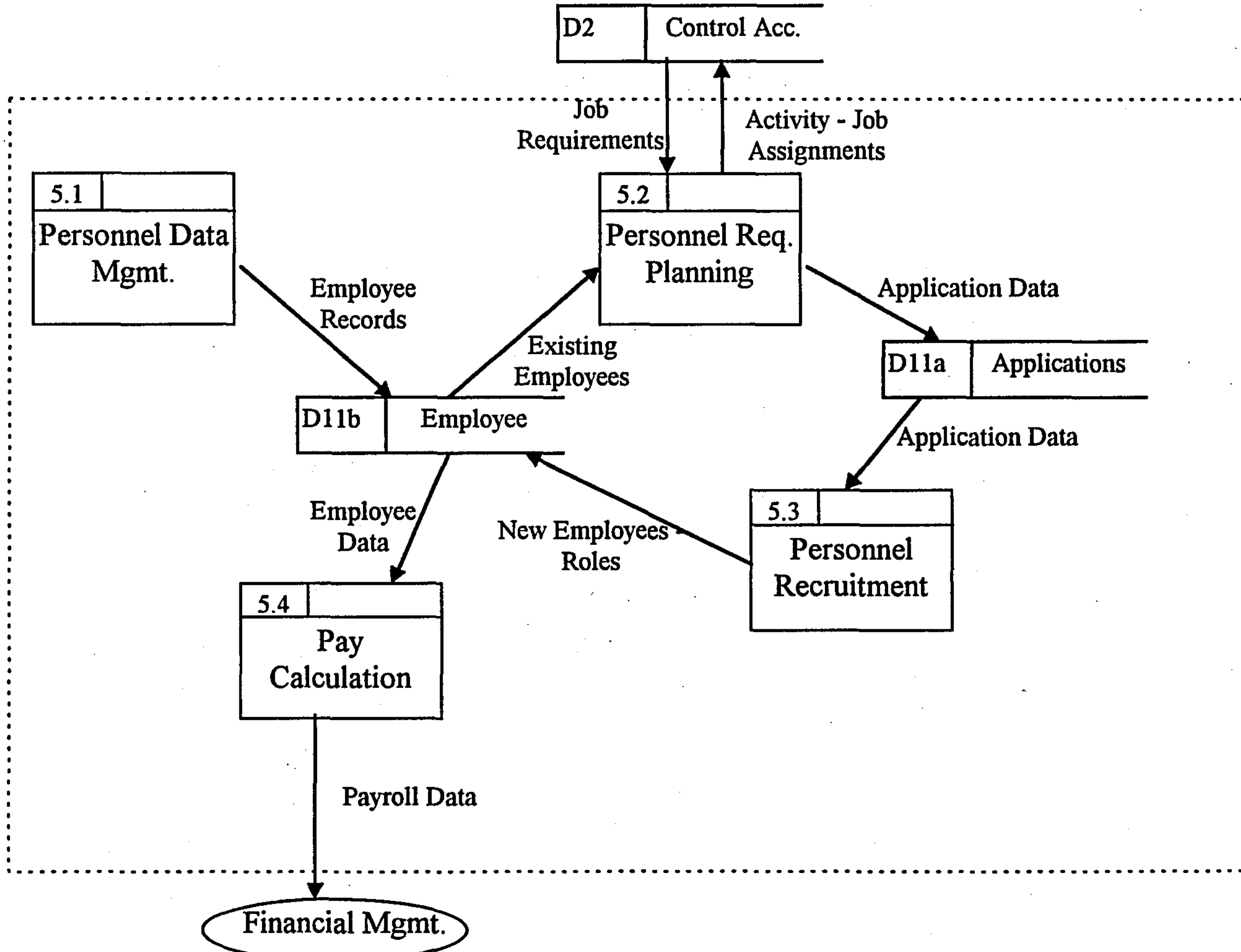


FIGURE A.7. Level-2 DFD of Human Resources Management

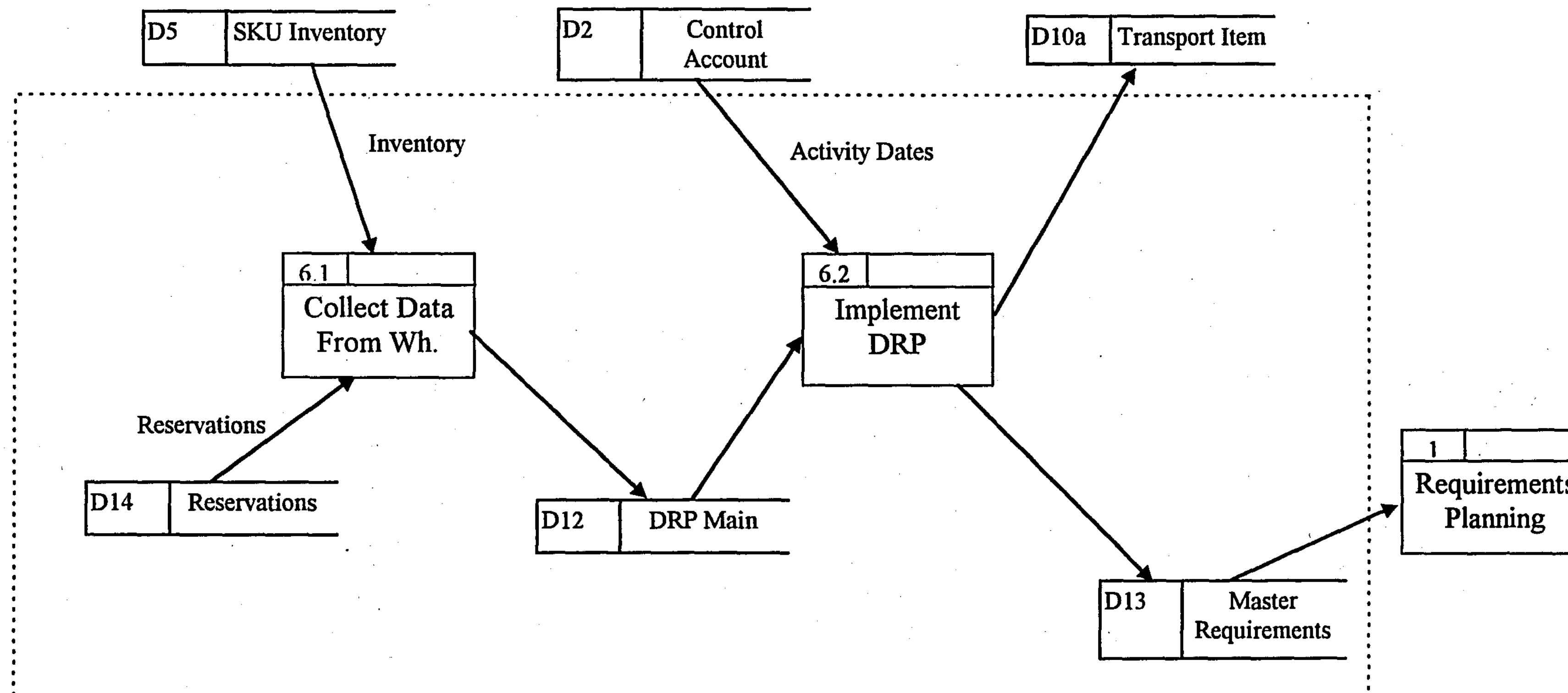


FIGURE A.8. Level-2 DFD of DRP Management

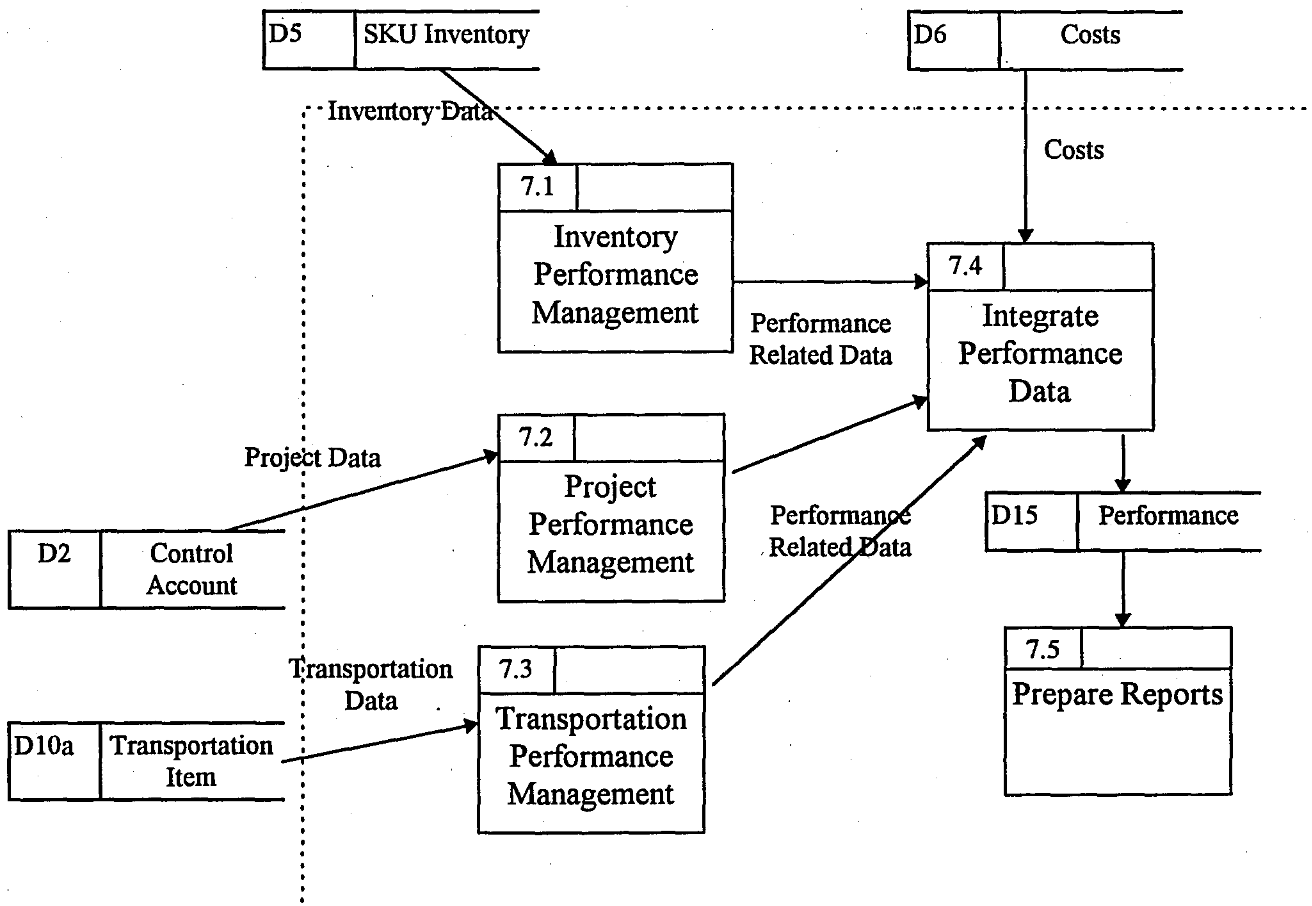


Figure A.9. Level-2 DFD of Performance Management

APPENDIX B

informix.material
mat_code TEXT(18)
name TEXT(20)
unit TEXT(8)
unit_weight DOUBLE
area CURRENCY
safety_stock DOUBLE
min_order_quant DOUBLE
max_order_quant DOUBLE
stor_cost_rate DOUBLE
signature INT
avgunitprice CURRENCY
lastbuyprice CURRENCY
lastindate DATE
lastoutdate DATE
lastsupno LONG
abc_cat TEXT(1)
subitem INT
storage_type TEXT(2)
pur_lead_time LONG
trans_lead_time LONG

informix.mat_char
mat_code TEXT(10)
char_code TEXT(10)
main_group TEXT(3)
subgroup1 TEXT(3)
subgroup2 TEXT(3)
maint_period DOUBLE
spec TEXT(10)

informix.currency_master
currency_code TEXT(3)
currency_desc TEXT(20)

informix.currency_detail
currency_code TEXT(3)
exchange_date DATE
exchange_rate DOUBLE

informix.project
project_code TEXT(3)
project_name TEXT(25)
proj_manager TEXT(40)
main_currency TEXT(3)

informix.control_acc
control_code TEXT(5)
project_code TEXT(3)
obs_code TEXT(5)
task_code TEXT(7)
start_event TEXT(5)
end_event TEXT(5)
actual_start_date DATE
actual_end_date DATE
early_start DATE
late_start DATE
status TEXT(8)
bcws DOUBLE
bcwp DOUBLE

informix.country
country_code TEXT(3)
country_desc TEXT(15)

informix.change_order
change_order_no TEXT(10)
change_type TEXT(1)
item_no TEXT(10)
co_by LONG

informix.subcontractor
project_code TEXT(3)
OBS_code TEXT(5)
subcont_code TEXT(5)
subcont_desc TEXT(40)

informix.obs
obs_code TEXT(5)
obs_descr TEXT(30)
level_of_detail INT
obs_parent_code TEXT(5)
subcontractor INT

informix.wbs
project_code TEXT(3)
wbs_code TEXT(5)
wbs_desc TEXT(30)
level_of_detail INT
wbs_parent_code TEXT(5)

informix.equipment
eq_code LONG
eq_desc TEXT(20)
eq_hourly_cost CURRENCY

informix.schedule_act
activity_code TEXT(5)
control_code TEXT(5)
activity_name TEXT(25)
early_start DATE
late_start DATE
early_finish DATE
late_finish DATE

informix.schedule_relation
relation_no LONG
pred_code TEXT(5)
succ_code TEXT(5)

informix.craft
project_code TEXT(3)
OBS_code TEXT(5)
craft_code TEXT(5)
craft_desc TEXT(40)

Figure B.1. Relational Tables (General)

informix.requisition_item
req_no LONG
mat_code TEXT(10)
mat_amount DOUBLE
arrival_date DATE
req_by LONG
req_location TEXT(3)

informix.inquiry_item
inq_no LONG
mat_code TEXT(10)
mat_amount DOUBLE
unit_price DOUBLE
currency TEXT(3)
period_grid_no LONG

informix.quote_item
quote_no LONG
mat_code TEXT(10)
mat_amount DOUBLE
period_grid_no LONG
unit_price DOUBLE
currency TEXT(3)
discount DOUBLE

informix.purc_order_item
pur_order_no LONG
mat_code TEXT(10)
sup_part_code TEXT(10)
mat_amount DOUBLE
unit_price DOUBLE
currency TEXT(3)
vat INT
payment_type TEXT(1)
bank_ref_no LONG
transport_no LONG
period_grid_no LONG
order_status TEXT(1)
est_rec_date DATE

informix.recv_slip_item
rcv_slip_no LONG
mat_code TEXT(10)
received_amount DOUBLE
amount_accepted DOUBLE
amount_rejected DOUBLE
quality_code LONG
rec_date DATE
packing_quantity DOUBLE

informix.requisition
req_no LONG
req_from TEXT(1)
req_to TEXT(5)
req_by LONG
project_code TEXT(3)

informix.inquiry
inq_no LONG
sup_no LONG
inq_date DATE
obs_no TEXT(5)

informix.quote
quote_no LONG
obs_no TEXT(5)
sup_no LONG
quote_date DATE

informix.purchase_order
order_no LONG
sup_no LONG
obs_no TEXT(5)
order_date DATE
order_by TEXT(5)

informix.purch_ord_asmt
pur_order_no LONG
inv_item_no LONG
mat_code TEXT(10)
quantity DOUBLE

informix.req_coverage
req_no LONG
pur_order_no LONG
mat_code TEXT(10)

informix.receiving
receive_no LONG
sup_no LONG
obs_no TEXT(5)
receive_date DATE

informix.supplier
sup_no LONG
name TEXT(20)
address TEXT(40)
contact_name TEXT(20)
account_no TEXT(10)
country_code TEXT(3)

informix.sup_char
sup_char_no LONG
cumulative_order DOUBLE
rel_of_deadlines DOUBLE
quality_code LONG

informix.supplier_terms
sup_terms_no LONG
transport_costs CURRENCY
currency TEXT(3)
price_sch_code LONG
inspection_code LONG

informix.period_grid
period_grid_no LONG
sup_terms LONG
rec_slip_item_no DOUBLE

informix.invoice
invoice_no LONG
sup_no LONG
obs_no TEXT(5)
invoice_date DATE

informix.invoice_item
item_no LONG
sup_invoice_no LONG
delivered_quant DOUBLE
unit_price DOUBLE
currency TEXT(3)
vat INT
discount INT
period_grid_no LONG
extension DOUBLE
rec_slip_item_no LONG
invoice_date DATE
po_number LONG

Figure B.2. Relational Tables - Purchasing

informix.route_data

route_no LONG
from TEXT(15)
to TEXT(15)
distance DOUBLE

informix.trans_supp

transup_code LONG
trans_name TEXT(20)
address TEXT(40)
country_code TEXT(3)

informix.shipment

shipment_no LONG
trans_firm_no LONG

informix.transport_master

bill_of_lading_no LONG
ship_via TEXT(10)
ship_no LONG
pl_ship_date DATE
act_ship_date DATE
pl_arr_date DATE
act_arrival_date DATE
fob_point TEXT(20)
freight_cost CURRENCY
currency TEXT(3)
status TEXT(1)

informix.vehicle_data

vehicle_no TEXT(10)
driver TEXT(30)
vehicle_type TEXT(10)
transup_code LONG

informix.route_details

bill_of_lading_no LONG route_detail_no INT
route_no LONG

informix.freight_rate

bill_of_lad_no LONG
transup_no TEXT(5)
route_no LONG
freight_rate CURRENCY
currency TEXT(3)

informix.account_payable

account_no LONG
supplier_no LONG
inv_item_no LONG
transport_no LONG
control_acc TEXT(5)
type TEXT(3)

informix.trans_asmt

bill_of_lading_no LONG pur_item_no LONG

Figure B.3. Relational Tables - Transportation Management

informix.sku
sku_code TEXT(6)
wh_code TEXT(3)
project_code TEXT(18)
mat_code TEXT(18)

informix.partial_delivery
pur_order_no LONG
rec_slip_no LONG
mat_code TEXT(10)
qty_dlvrd DOUBLE

informix.warehouse
wh_code TEXT(3)
wh_name TEXT(20)
location_code TEXT(3)
responsible_code LONG
space_capacity DOUBLE

informix.inventory_level
wh_code TEXT(3)
sku_code TEXT(6)
item_no INT
quality_id TEXT(15)
mat_on_hand LONG
reserve_stock DOUBLE
width DOUBLE
length DOUBLE

informix.quality
inspect_code LONG
inspect_by DOUBLE
mat_accepted DOUBLE
mat_backordered DOUBLE

informix.location
location_code TEXT(3)
location_desc TEXT(20)

informix.invent_cov
req_no LONG
mat_code TEXT(10)
sku_code TEXT(6)
quantity DOUBLE

informix.task_code
task_code LONG
control_code TEXT(5)
description TEXT(20)

informix.reservation
reservation_no LONG
reserved_by LONG
control_acc_code TEXT(5)
stock_mov_no LONG
res_date DATE
sku_code TEXT(6)
amount LONG
item_no LONG

informix.control_equip
control_code TEXT(5)
equip_code TEXT(18)
hours_used DOUBLE
used_date DATE

informix.control_material
control_code TEXT(5)
material_code TEXT(10)
mat_amount DOUBLE

informix.inven_addition
sku_code TEXT(6)
rec_slip_item_no LONG
material_amount DOUBLE
inspect_code DOUBLE

Figure B.4. Relational Tables - Site&Warehouse Materials Management

informix.warehouse_ent
enty_code LONG mat_code TEXT(10) warehouse_code TEXT(3) movement_date DATE
mat_amount DOUBLE project_code TEXT(3) movement_by LONG field_return INT

informix.warehouse_leave
leave_code LONG warehouse_code TEXT(3) movement_date DATE
mat_code TEXT(10) mat_amount DOUBLE project_code TEXT(3) movement_by LONG

informix.stock_mov
mov_no TEXT(1)
movement_date DATE quantity DOUBLE

informix.handl_op
fr_station LONG to_station LONG oper_date DATE
duration DATE

informix.pallet_type
pal_type_no LONG
pal_name TEXT(20) height DOUBLE width DOUBLE length DOUBLE

informix.pallet_tracking
pallet_type LONG sku_no TEXT(6)

informix.station
station_no LONG
station_type TEXT(10) SKU_no TEXT(6)

informix.pal_type_asmt
stor_area_no LONG pal_type_no LONG mat_code TEXT(18)

informix.storage_area
stor_area_no LONG
SKU_code TEXT(6) stor_capacity DOUBLE unit TEXT(3)

Figure B.4. Relational Tables - Site&Warehouse Materials Management (Continued)

informix.employee
emp_code LONG
employee_name TEXT(20)
obs_no TEXT(5)
address TEXT(40)
sex TEXT(6)
date_of_birth DATE
title TEXT(20)
wage_group LONG

informix.employee-craft
emp_code LONG
craft_code LONG

informix.skill
emp_code LONG
char_code LONG

informix.payroll_acc
emp_code LONG
month DATE
amount_total MONEY
amount_net MONEY

informix.req_profile
char_code LONG
task_code LONG

informix.emp_char
emp_code LONG
char_code LONG
age LONG
hiring_date DATE
prev_employer TEXT(20)
foreign_lang TEXT(30)

informix.time_account
emp_code LONG
control_code TEXT(5)
work_date DATE
hours_wor INT

informix.person_req
obs_code TEXT(5)
type_required LONG
amount INT
req_date DATE

informix.wage_group
wage_group_no LONG
project_wage_rate DOUBLE
overtime_pay DOUBLE
income_tax_class TEXT(3)
tax_free_all DOUBLE
cum_tax DOUBLE

informix.applicant
appl_code LONG
appl_name TEXT(20)
address TEXT(40)
sex TEXT(6)
date_of_birth DATE

Figure B.5. Relational Tables - Human Resource Management

informix.perform_master
project_code TEXT(3)
perform_code TEXT(5)
start_date DATE
end_date DATE
bcws DOUBLE

informix.trans_perf
trans_perf_code DOUBLE
mas_perform_code TEXT(5)
per_on_time INT
trans_cost DOUBLE

informix.project_perf
proj_perf_code DOUBLE
mas_perform_code TEXT(5)
start_date DATE
end_date DATE
per_complete INT
bcwp DOUBLE
spi INT
cpi INT

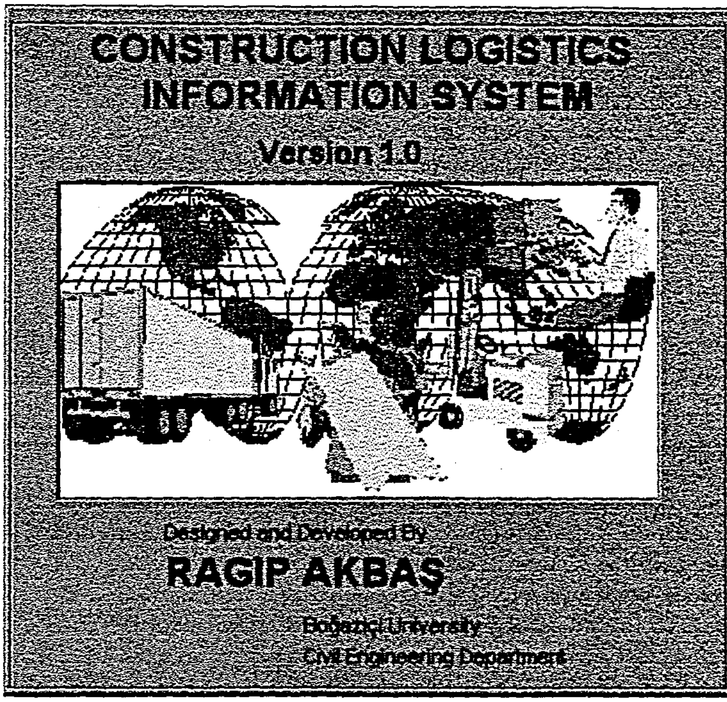
informix.drp_main
requisition_no LONG
date DATE
gross_req DOUBLE
unit TEXT(5)

informix.drp_tree
sku_code TEXT(6)
parent_code TEXT(6)
level_of_detail LONG

informix.warehouse_perf
wrh_perf_code DOUBLE
mas_perform_code TEXT(5)
wh_code
percent_sat INT
wh_cost DOUBLE

Figure B.6. Relational Tables - Performance Management and DRP

APPENDIX C



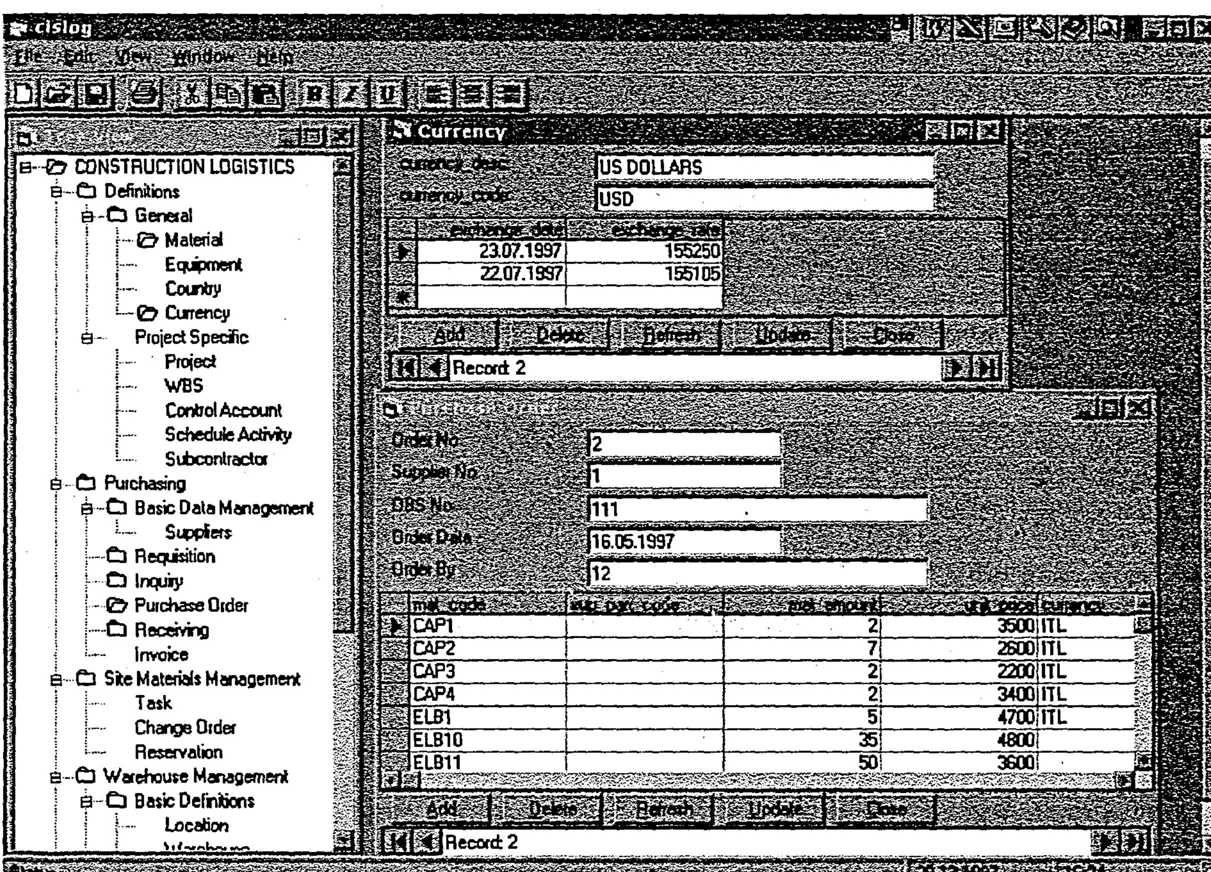
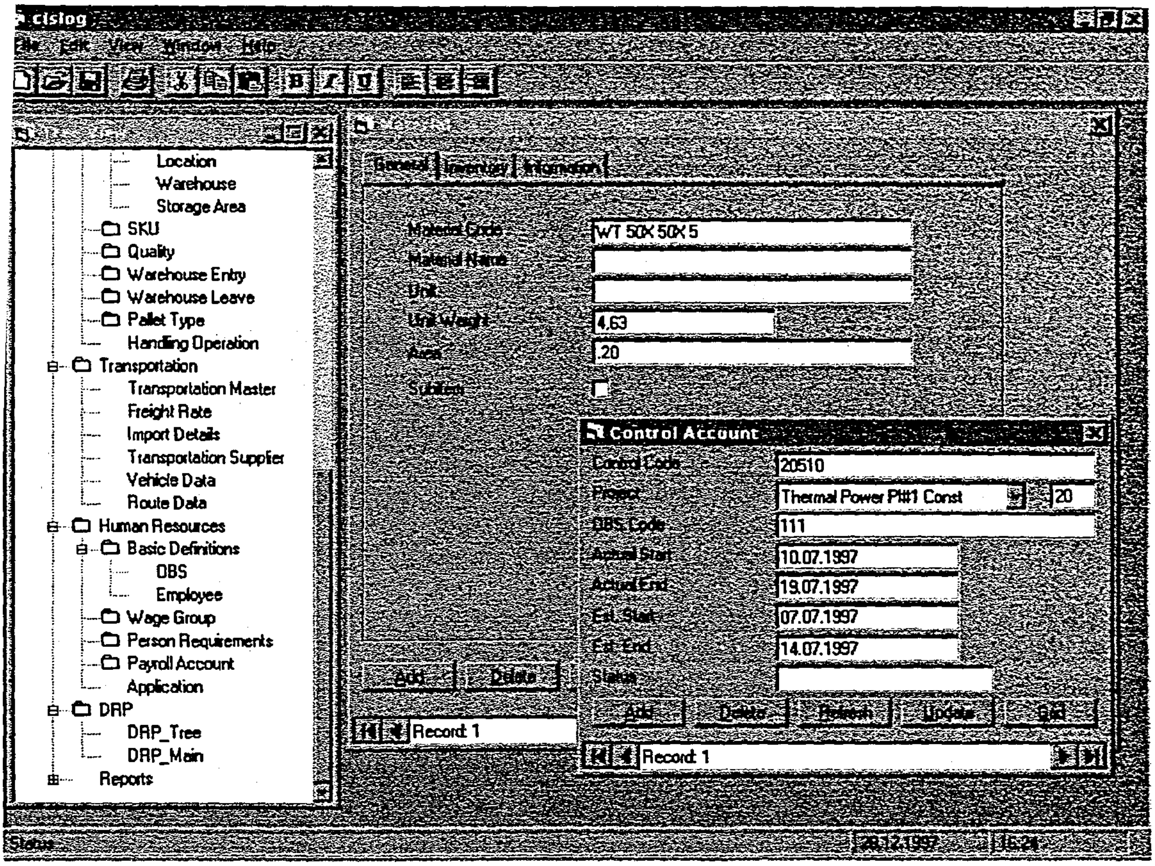


Figure C.1. Construction Logistics Software Screen Shots



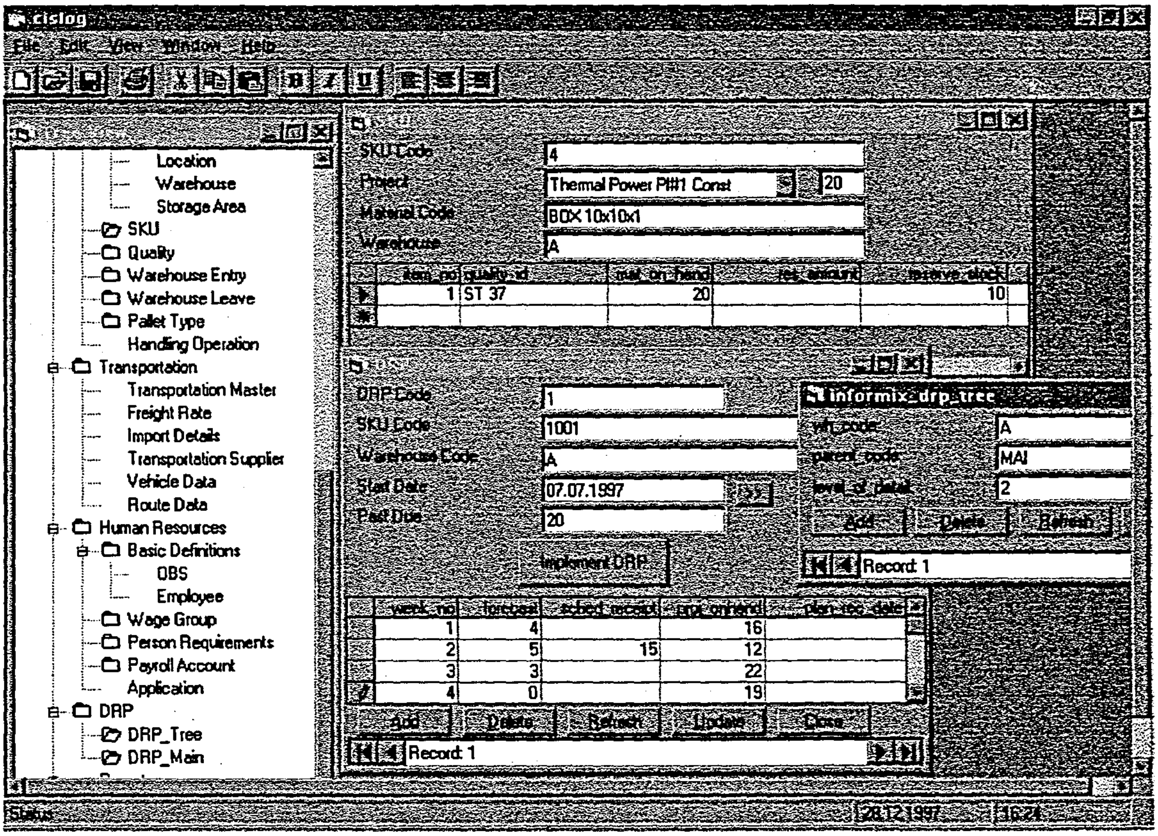


Figure C.1. Construction Logistics Software Screen Shots(Continued)

informix_sku : Tablo

sku_code	project_code	mat_code	wh_code
1	20	BOX 100x100x	A
2	20	BOX 100x50x3	A
3	20	BOX 100x50x4	A
4	20	BOX 10x10x1	A
5	20	BOX 450x250x	A
6	20	BOX 60x40x2.5	A
7	20	BOX 80x40x3	A
8	20	CIR 12	A
9	20	CIR 125	A
10	20	CIR 210	A
11	20	CIR 22	A
12	20	CIR 30	A
13	20	CIR 35	A

Kayıt: 1

informix_requisition_item : Tablo

req_no	mat_code	mat_amount	an
201	CAP1	2	
201	CAP2	7	
201	CAP3	2	
201	CAP4	2	
201	ELB1	5	
201	ELB10	35	
201	ELB11	50	
201	ELB12	26	
201	ELB13	5	
201	ELB14	4	
201	ELB15	15	

Kayıt: 1

informix_inventory_level : Tablo

wh_code	sku_code	item_no	quality_id	mat_on_hand	res_amount	reserve_stock
A	55	1	ST 37	1		10
A	55	2	ST 37 RED	3		3
A	56	1	ST 37 TEZGAH	1		2
A	56	2	ST 37 TEZGAH	1		10
A	57	1	ST 37	3		5
A	58	1	ST 37	2		10
A	59	1	ST 37	1		10
A	60	1	ST 37	1		4
A	61	1	ST 37	1		10
A	52	3	ST 37 TEZGAH	2		5
A	90	1	ST 37	17		15
A	85	6	ST 37	8		10
A	85	7	ST 37	1		10

Kayıt: 39

Figure C.2. Example Data from Tables

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