A FRAMEWORK FOR A DECISION SUPPORT MODEL FOR SUPPLY CHAIN MANAGEMENT IN THE CONSTRUCTION INDUSTRY

by

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Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Environmental Design and Planning

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November, 2004

Blacksburg, Virginia

Keywords: Supply Chain, Material Management, Electrical Contractors, Construction, Decision Modeling, Decision Analysis, Knowledge Management, Information Technology

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ABSTRACT

Materials are one of the areas that require special attention while creating a project's master plan as well as during the daily construction progress. The absence of materials when needed is one of the main causes of loss of productivity at a jobsite. Inefficient materials management can lead to an increase of 50% in work hours. As a result, a detailed plan for the materials management of each construction project is necessary.

The critical role of materials management in the success of a construction project motivates the development of a new framework for the process of materials management for the construction industry, specifically the electrical construction industry. Materials management problems have a great impact on general contractors, but are more critical for specialty contractors such as electrical contractors. Based on the co-authors' experience, the construction industry has moved toward specialty contractors in the last decade to the point where at least 80% of the work performed on a typical construction contract is done by specialty contractors. General contractors have become, for the most part, project managers.

Currently, materials management functions in the construction industry are often performed on a fragmented basis with minimal communication and no clearly established responsibilities among the parties involved. In addition, the collaboration required among departments has not been considered and implemented. This fragmentation creates gaps in information flow, which leads to delays in material ordering and receiving, expediting costs, excessive inventories of some items and project delays. However, model-based, computerized solutions to materials management problems are proliferating. Unfortunately, the typical electrical contractor may be overwhelmed by the technology required by these solutions and the challenges of implementing them into their business practices. A way out of this dilemma is presented by designing an industry-specific

framework for the development of computerized decision support systems for the supply chains of the electrical contracting industry. Decision models are ever-present in the materials management processes of industries other than construction and have proven their worth in improving productivity and profitability. Knowledge-management concepts were applied to design an integrated, effective system of decision-support tools for materials-management decisions of an electrical contractor during the construction phase of a project.

The framework developed is valuable in two fundamental ways. First, the framework identifies and describes all phases of materials management for an integrated, holistic view of all factors that affect the total cost of materials and material shortages. The research created detailed mappings of the essential decisions, decision models and data that are required to support supply-chain activities of construction contractors throughout a project life cycle.

Second, the framework differentiates those steps in the materials management process that are straightforward applications of methods from those steps that are decisions. For these decisions, that are critical to the performance of the materials management process, we introduce the concept of a decision model and describe how such models can be incorporated into an advanced materials management system. This phase of the research developed a structured systems design of distributed, integrated decision support systems for materials management of the electrical contractor. The research derives the optimal integration of people, decision processes, decision support systems and data that are required to support efficient and effective systems for acquisition, procurement, transport, storage and allocation of material in the construction industry.

"The construction industry is as much a manager of information as it is a manager of materials"

- John Hollingworth

(Building Centre Trust, 1990)

DEDICATION

To Arliz, Gaby, Amanda and Cristian

Nancy (†) you'll always be with us

ACKNOWLEDGEMENTS

First of all I would like to thank God for what I am, for everything I have, for taking care of my family and for being everything.

Thanks to my committee members who assisted and guided me to complete this work. The guidance, inspiration and encouragement of Drs. Walid Thabet and Ralph Badinelli are greatly appreciated. The continued interest, assistance, and inspiration of Dr. Flynn Auchey, Dr. Yvan Beliveau and Dr. Julio Martinez are deeply appreciated. Thank you for being part of my committee and for the great relationship that grew among us. I would say that I consider you my friends.

Special thanks to Dr. Walid Thabet, the chairman of my advisory committee, and to Dr. Ralph Badinelli, who was like a co-chairman, for their continuous guidance, support in all aspects, and for all the time spent helping me to finish this research and the subsequent document. Thank you for always having time for me, for the countless hours that we spent discussing ideas, and for the extensive time dedicated to review the document. Thank you for being my mentors and for the friendship that you offered me.

I would like to extend my gratitude to my friends and colleagues from the Department of Building Construction, specially Brendan, Fairuz, Svetlana and Brett. Also thanks to my dear friends Vineet and Sonia. You always had words of encouragement when things were rough.

The support of the University of Puerto Rico at Mayagüez is deeply appreciated.

The support of the National Electrical Contracting Association (NECA), Electrical Contracting Foundation- ELECTRI' 21 is deeply appreciated.

Thanks to the following companies that allow me to collect data through interviews and site visits: Dynalectric, TradePower, Truland Systems, J.E. Richards Inc., Graybar, Starr

Corporation, Crescent Electrical Supply, A.C. Corp., Home Depot, New River Electrical, Varney Electric, Amprite Inc., Square D, Accubid Systems

I would also like to thank my parents and all my family in Puerto Rico for their unconditional support, encouragement and love for my family and me.

Thanks to our friends Nicole, Tony, Valerie, Joe and their kids for being there with us when we needed them the most. Your encouragement and friendship helped us to live through the immense pain that we were feeling.

To my mother in-law Nancy (†): when things were rough, you always fought to be with us. God knows better and you are in a better place now. The suffering is over, although we miss you dearly. Thank you for everything you did for us.

Finally, I would like to thank my wife Arliz, my kids Gaby, Amanda and Cristian for their love, support and for tolerating the days and nights that I spent working with my research. You put a smile on my face every time that the research was driving me crazy. This work is dedicated to you.

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CHAPTER ONE: RESEARCH STATEMENT

1.1 Introduction

Supply chain management can be defined in terms of the managerial decisions that create and regulate the supply chain. Among these decisions are sourcing, forecasting, batch sizing, safety-stock setting, order timing and locating stock. In recent years, supply chain management (SCM) has emerged as a critically important aspect of an electrical contractor's business viability. Competitive advantage can be achieved through: 1) reducing or avoiding material shortages that delay projects and degrade the reputation of the contractor, and 2) reducing or avoiding excess material stock that is costly to store, transport and finance.

Although material management problems highly impact general contractors, they are more critical for specialty contractors including electrical contractors. Most electrical contracting companies are small in size. Therefore, they have to efficiently manage their materials to lower cost in order to remain in business. Because of the risk that electrical contractors undertake in every construction job, they are constantly tracking their resources particularly their material. This tracking is useful to avoid losing material due to theft, misplacement or damage, to improve productivity, and to compare actual resource and labor usage against planned values. In addition, tracking allows materials for identifying when materials need to be ordered, based on actual usage of materials on site and progress of the work. Other challenges encountered include dealing with suppliers, on site materials handling, storage, and handling of material surplus.

1.2 Problem Statement

Current materials management practices in the electrical contracting industry are performed on a fragmented basis with unstructured communication and no clearly established responsibilities between the parties involved. This fragmentation creates gaps in information flow, which affects the decision making process and lead to delays in material ordering and receiving, among other problems. The material manager needs to realize that decisions taken at one stage in the process will certainly impact other activities and processes in the supply chain, a problem not realized due to this fragmentation.

The initial phase of this research investigated current material management practices in the Electrical Contracting industry. The investigation considered the entire range of activities necessary for procuring the needed material, starting with the estimating process and ending with site delivery, distribution and storage logistics. Research outcomes included documenting the problem bottlenecks in the supply chain as well as identifying and classifying the various criteria that influence the decision process for procuring material. A comprehensive flowchart describing the material supply chain process was developed based on various discussions and interviews with several National Electrical Contracting Association (NECA) members. The flowchart considered many decision alternatives including material type, supplier availability and relationship, procurement options and incentives, quantities needed, delivery dates, storage alternatives, and project schedules.

- Figure 1.1 depicts a detailed material management flowchart for a typical electrical contractor that specializes in commercial construction. The flowchart was developed through several interviews with office and site personnel of various electrical contracting companies in the Northern Virginia (NOVA), Southwest Virginia, Tennessee, Maryland and North Carolina areas. Flowcharts prepared for the companies, narratives and questionnaires used during the interviews and site visits are available in the Appendix. From the information acquired from these interviews, five distinct phases that comprise the process were identified: 1-Bidding Phase, 2-Sourcing Phase, 3-Materials Procurement, 4-Construction Phase, 5-Post-Construction Phase. The flowchart identifies several decision nodes, in each phase, requiring alternative management actions to be taken.

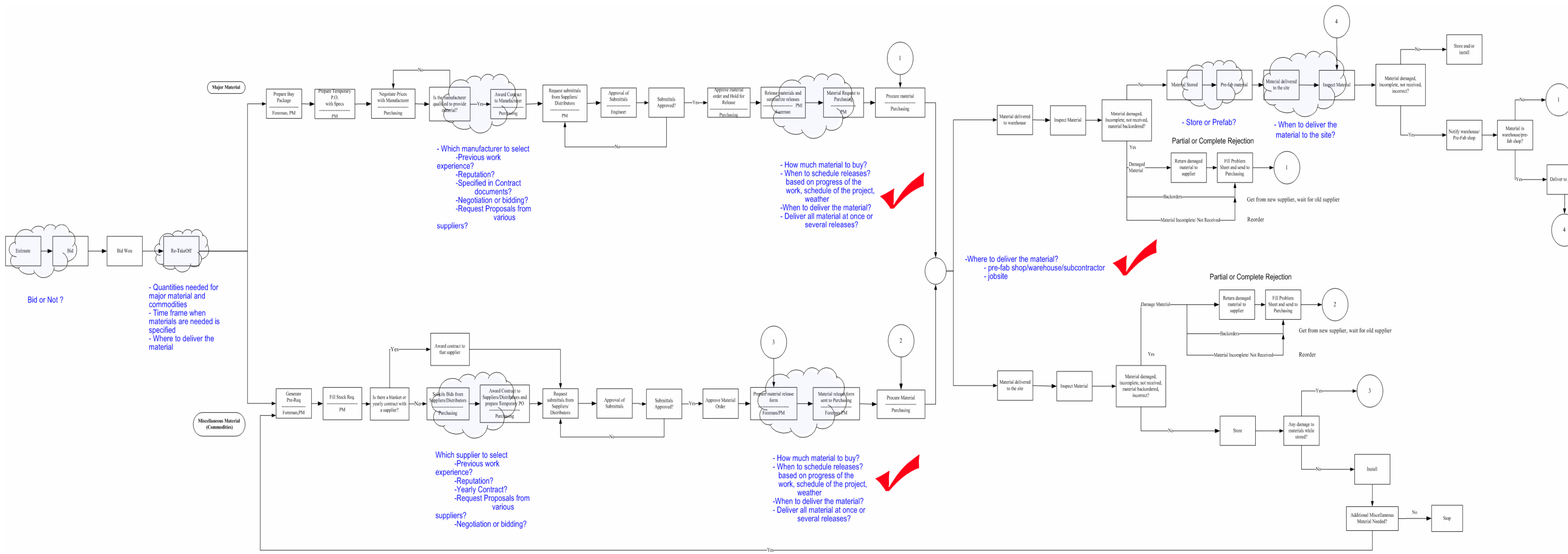

Figure 1.1: Detailed Material Management Flowchart

Decision nodes identified include supplier selection, material procurement (where to buy from, how much to buy, when to buy) and delivery options, and storage alternatives. Actions to be taken at every decision node are complex because of their dependency on many other factors that could represent constraints or alternatives.

Many challenges are encountered during the various phases of the material management process including challenges with bid procurement, material procurement, and material storage and distribution. Examples of challenges include:

- Bid procurement challenges- During budget negotiation, the general contractor may be forced to cut costs to satisfy budget limits of owners while still committing to the same scope of work. The electrical contractor is usually one of the last trades to be procured in a project and in many times is asked by the general contractor (GC), prior to finalizing the sub-contract, to absorb some of the cost reductions. This puts even more pressure on the electrical contractor to complete the scope of work for a lower cost than what was initially budgeted.
- Supplier selection challenges- The selection of a reputable supplier is critical for ensuring that materials are delivered in the quantities needed and at the dates specified.
- Material purchasing challenges- Once a supplier is selected, the contractor has to systematically follow up the status of ordered material in order to assure that the material arrives to the job site in the quantities and dates specified.
- Jobsite storage and handling challenges- The majority of the problems faced by electrical contractors with respect to materials management are encountered at the job site and include tracking of material, storage issues, material distribution and re-handling.

The challenges related to the material management practices in the electrical contracting industry are further analyzed and discussed in Chapter 5.

The material procurement (ordering and delivery) phase is very critical to the successful execution and completion of any project. The person in charge of procuring materials or the purchasing department, in the case of a large company, needs to ensure that the correct materials in the correct quantities are ordered. They also need to verify the release dates at which the material is needed and clearly specify those delivery dates as well as the location of delivery to the supplier.

The focus of the procurement decision node includes how much material to buy, when to buy this material, which supplier to choose and where to deliver this material. The decision of how much to buy is very important to assure that material quantities needed are available and that there are no material shortages. From the interviews, it was found that most of the electrical contractors buy large amounts of their material early based on field personnel purchase requests without planning which quantity is needed. This results in additional costs associated with storage fees, damage during storage, and re-handling due to space limitations. Electrical contractors believe that these costs are minor when compared to delays and labor costs if the material is not available when needed.

The decision of when to buy is important to ensure that material is available when needed. In many companies, this process starts with the generation of a material requisition schedule (e.g. release forms) specifying material types, quantities needed and dates of when the material should be delivered. In large jobs, the schedule is usually prepared by the site staff then sent to the purchasing department to request the material from the suppliers/distributors under contract. In smaller companies or smaller size jobs, material may be procured directly by the field personnel. To avoid surplus, many contractors request about 80% of planned material needed. Additional quantities are purchased when the job is near completion and a better estimate is realized.

The selection of suppliers is primarily based on lowest price. However, contractors may consider suppliers with higher prices that will provide better service or that have a record to supply the right material in the quantities needed at the times specified. If there are no qualified suppliers from the proposals received, the contractor should request bids from other suppliers. In some situations the contractor might enter into a blanket or yearly contract. This is a common practice used in purchasing miscellaneous material. Yearly contracts guarantee the price, availability and delivery of the specified materials and equipment. This approach also reduces the company's risk of stock-outs and procurement costs because time and paperwork are reduced.

The decision of where to deliver the material requires space planning and consideration of site limitations, pre-fabrication strategies, and subcontractors to be used. Material is generally requested for delivery to the job site. From the site visits to some projects, it was observed that in many instances the material was stored in "sea cans" located far away from the jobsite. This increases the potential of material loss due to theft. Regarding material stored in the work area, this was done without proper planning, and material needs to be moved to free space so that other trades can work in the area. The costs associated with re-handling, loss and/or theft are not realized when ordering the material. The electrical contractor could use better procurement policies to avoid having over-stocking of inventory on the jobsite, and to decrease inventory costs. However, the effort of changing ordering policies will require a commitment of delivery when needed by the supplier. Another approach that could be used to decrease inventory is called vendor managed inventory (VMI). When this approach is used, the distributor places a trailer on site with the needed materials and equipment and takes the responsibility of maintaining the inventory throughout the project. The distributor charges the contractor for materials and equipment used at predetermined prices. At the end of the project, the distributor removes the trailer along with the unused inventory. The company can outsource their warehouse operation to the distributor.

In some instances delivering material directly to the jobsite may not be feasible due to storage or access limitations. In this case, the material is delivered to other locations such as the contractor's warehouse or another subcontractor storage area. Material is delivered to a warehouse in cases such as when critical specialty items are ordered early and are not going to be installed immediately, when storage area at the job-site is unavailable, or if the material will be used for pre-fabrication. Storage of the material at the warehouse prior to moving it to the jobsite increases indirect costs due to re-handling. Some companies utilize a pre-fabrication shop facility to assemble components in a controlled environment. In some instances, the material is sent to a subcontractor for temporary storage at his facility prior to delivery and installation. There are additional costs associated using the subcontractor's storage yard, but since he is already contracted for installation these fees are smaller compared to using an independent storage facility. The current material management practices in the electrical contracting industry will be discussed further in Chapter 4.

Material procurement problems greatly affect the construction stage and failure to manage this phase effectively could result in project disruption and possible delays due to late deliveries, stockouts due to small quantities bought, material delivered to the wrong locations, material backordered and overall costs. The contractor has to systematically follow up the status of ordered material to assure that the material arrives to the job site in the quantities and dates specified. Expediting is one control system necessary to assure a timely equipment and materials arrival to achieve a project completion on schedule. Expediting involves monitoring all steps in the procurement cycle, with special focus on those involving the vendor or subcontractor, to assure reliable, economical, on-schedule delivery.

Ensuring that material deliveries occur on a timely basis is a very difficult task. As revisions come through from material takeoff, it is all too easy for this to impact on material deliveries, resulting in them arriving late or in insufficient quantities. The impact of schedule changes can have a similar effect. While material may originally have been ordered in good time, this may no longer be the case. Design changes may result in a reduction in requirements for some material and an increase for others, which will also affect the delivery schedule. These changes can have a considerable impact on cost and evaluating the full impact of the changes is extremely important. Material may not arrive on time, work may have to begin out of sequence, or the fabrication process may be delayed.

Effective planning and communication is required to keep costs to a minimum, to minimize errors in ordering and to increase the probability that the material is on site when needed. Constant communication and clearly specifying, without ambiguities, the material needed could help to minimize errors in ordering.

1.3 Research Objective

The objective of this research is to improve the decision making process for supply chain management in the electrical contracting industry. This objective can be broken down into the following components:

- Identify bottlenecks in the current decision making process for material management for the electrical contractor.
- Develop responses to the bottlenecks in currents practices. This will require identifying in greater detail the decision nodes in the material supply chain for the electrical contractor.
- Apply knowledge-management and decision-modeling techniques concepts to design an integrated, effective system of decision-support tools for the material supply chain of the electrical contractor.
- Identify all of the knowledge elements that constitute the alternatives, factors or parameters and performance measures for each decision node.
- Develop decision making flowcharts that describe the material management decision making process for the decision nodes considered in the study. These flowcharts will also describe the relationships between the knowledge elements graphically.

1.4 Research Contribution

The main contribution of this research is the identification of bottlenecks in the supply chain management process and the development of a new decision model for the EC industry. This contribution is comprised by:

1. The design of an industry-specific framework for the development of structured systems design of distributed, integrated computerized decision support systems for the supply chains of the electrical contracting industry.

   The framework developed is valuable in two fundamental ways. First, the framework identifies and describes all phases of materials management for an integrated, holistic view of all factors that affect the total cost of materials and material shortages. The research created detailed mappings of the essential decisions, decision models and data that are required to support supply-chain activities of construction contractors throughout a project life cycle.

Second, the framework differentiates those steps in the materials management process that are straightforward applications of methods from those steps that are decisions. For these decisions, that are critical to the performance of the materials management process, the research introduces the concept of a decision model and describes how such models can be incorporated into an advanced materials management system. This phase of the research developed a structured systems design of distributed, integrated decision support systems for materials management of the electrical contractor. The research derives the most favorable integration of people, decision processes, decision support systems and data that are required to support efficient and effective systems for acquisition, procurement, transport, storage and allocation of material in the construction industry.

2. The identification of the current material management practices for the electrical contracting industry and the representation of these practices in a graphical way by the development of the flowcharts presented in Chapter Four. By doing the graphical representation of the current process, the framework addresses a fundamental and critical aspect, which is that in order to improve a process it is very important to know how it works.
3. The identification of decision nodes in the current material management practices for the electrical contractor. More specifically, identifying which are the important questions and aspects related to decision making for material supply chain in the electrical contracting industry.
4. The development of SPARCS, Supply Chain Parameter Classification System, is another contribution of this study. SPARCS is a hierarchical structure for classifying parameters for material supply chain, specifically for the electrical contracting industry. Up to the development of SPARCS, there was no structured approach to categorize the parameters that need to be considered on the supply chain decision making process for the electrical contractor. The development of SPARCS provides the following contributions:

A. SPARCS defines the database that would be extracted from ERP databases or other company data sources in order to support specific decisions.
B. SPARCS defines data that may have to be extracted from different corporate entities and different corporate databases (general contractor, sub contractor, suppliers, and owner).
C. SPARCS assists in the development of small-scale decision support that a sub-contractor may utilize in the absence of an ERP system.

5. The definition of the data, models, decision makers and procedures that make up the knowledge and a mapping of their relationships is another contribution of this study. The identification and collection of all the knowledge elements, through interviews with electrical contractors, suppliers and manufacturers, that constitute the alternatives, factors or parameters and performance measures, allowed using practical data in the development of the framework. The framework not only identified knowledge elements required for the overall material management system, but, in addition, knowledge elements that are related to each decision independently were also identified.
6. The perspective held by many people within and outside the construction industry has been that this industry is different from other manufacturing and service industries. This perspective has created barriers to the adaptation of methods and technologies that are emerging in these other industries. This research breached some of these barriers by working with companies from the electrical contracting industry in the design of the framework for implementing supply-chain practices. The methodology used in the research allowed considering and including the perspective and concepts used by the contractors in this sector. The relationship with the industry contractors, allows continuous learning for these contractors of new technologies and methods for supply-chain management as they were exposed, through the interviews conducted as part of the research, to some of the practices used in manufacturing and other industries.

1.5 Justification

The success of a construction project resides in the ability to plan effectively how to manage resources and people and on the successful implementation of the plan. This grand plan includes the determination of the tasks to be performed, their sequence and strategies for allocation of resources among them. The grand plan is subdivided into smaller plans to facilitate managing the entire project. The quality and effectiveness of the grand plan or individual plans can be measured, among other things, by variability of the time and cost required to complete it, compared to the original estimates.

Construction projects are subjected to continuous variability. This variability can be traced to the dependency of the general contractor on other parties such as suppliers and subcontractors. As a result of deviations from the plan, decreases in productivity and subsequent increases in cost and time required to finish the project can be expected. Materials are one of the areas that require special attention while creating the grand plan for the project. Materials account for more than 50% of the total cost of a construction project. In addition, materials are essential for the daily progress of a construction project. The absence of materials when needed is one of the main causes of loss of productivity in a jobsite. As a result, an elaborate plan for materials management becomes mandatory. The formulation of a plan for materials management involves the development of strategies for the integration and monitoring of the entire process and the implementation of those strategies. This plan should consider, among other things, the flow of materials through all the phases of the project starting from the estimating phase, through procurement, purchasing, delivery, installation and disposal of surpluses as shown in Figure 1.2. General activities that should be considered in preparing the plan for materials include the determination of materials needed (i.e. quantity, type, sizes, color, etc.), specific dates when the materials are needed, procurement, expediting, receiving, storage, usage, disposal and provisions for contingencies.

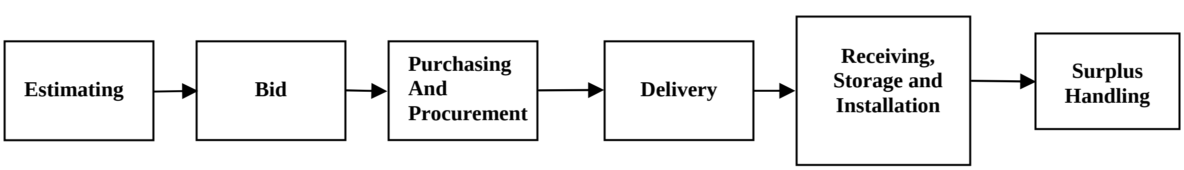

Figure 1.2: Material Cycle in a Construction Project

The accuracy of the plan is evaluated by variations from the estimated cost, variations on the delivery date, and effects of the variations in time of material management related activities on the overall project duration (i.e. on time vs. delayed). Based on the deviations observed, the materials manager may decide to modify certain decisions or strategies and/or formulate a new plan. This comparison of planned strategies vs. actual results is essential to refine and update the materials management plan. In addition, during the material cycle on the construction project, the project team faces decisions about deliveries, suppliers, among others.

Better materials management practices and decision-making models could increase efficiency in operations and reduce overall costs. There is a growing awareness in the electrical contracting industry that materials management needs to be addressed as a comprehensive integrated management activity. Increasing pressures on project costs and completion times are motivating the need to make supply-chain decisions in a coordinated fashion and in consideration of minimizing total supply-chain cost without causing shortages. The performance of these decisions is heavily dependent on the combination of the different alternatives listed in every phase of the materials management process. Currently, there is no structured approach to identifying the optimum combination of decisions that will lead to processing the needed material with the least total costs. Fortunately, model-based, computerized solutions to supply-chain problems are proliferating. However, the typical EC may be overwhelmed by the technology embodied by these solutions and the challenges of integrating this knowledge into business practices. A definition of the data, models, decision makers and procedures that make up this knowledge and a mapping of their relationships and uses is a vital first step towards building integrated decision support for the electrical contractor.

It is clear that effective planning is required to keep costs to a minimum and to insure that the material is on site when needed. Poor planning of materials will increase indirect costs associated with delivery and use of materials. In addition, losses in productivity, delays, re-handling, and duplicate orders among other factors can be expected when there is a poor materials management system. The electrical contractors need to realize that by improving their material management systems improvements could be achieved in other areas such as in the labor force. The effects of not having material available when needed are could be difficult to measure, but the impact in labor productivity could be noticed and quantified. Indirect labor cost due to absence of materials could be significant. Increases in idle time and/or unproductive time should be expected. Crew members will pretend to be busy even if there is no material to install, which increases the labor cost.

Stukhart, G. and Bell, L.C. (1987) conducted a study of twenty heavy construction sites where the following benefits from the introduction of materials management systems were noted:

- In one project, a 6% reduction in craft labor costs occurred due to the availability of materials on site when needed. On some other projects, an 8% savings was estimated by reducing the delay for materials.
- Two projects, with and without a materials management system, were compared and the comparison revealed a change in productivity from 1.92 man-hours per unit without a system to 1.14 man-hours per unit with a new system. Much of the difference can be attributed to the timely availability of materials.
- Warehouse costs were found to decrease 50% on one project with the introduction of improved inventory management, representing a savings of $92,000. Interest charges for inventory also declined, with one project reporting a cash flow savings of $85,000 from improved materials management.

Other issues that could be a consequence of a bad material management system include disruptions of work flow, time lost due to relocation of the work force, changing set ups to new locations where material is available, even if it is different activity, de-motivation of supervisors and possibly labor force. On the other hand, excess of material due to early deliveries could disrupt the work flow, require re-handling material to free up space for other crews to work, which requires time, the possibility of material being damaged increases and there is a greater probability of having accidents due to extra material on the jobsite.

1.6 Methodology

A plan of work for the research that identified the tasks that needed to be accomplished to design the proposed decision model for material procurement was prepared. The first task in the development of the framework was to build on the findings of previous research (Thabet and Perdomo, 2003) and conduct additional interviews that will allow identifying the bottlenecks in the current material management process.

The second task was to identify in greater detail the decision nodes in the material supply chain for the electrical contractor. Decision nodes are those junctures in the material management process where a decision has to be made with material such as supplier selection, material procurement (who to buy from, how much to buy, when to buy), delivery options, and storage alternatives. Figure 1.3 depicts a decision node for material ordering.

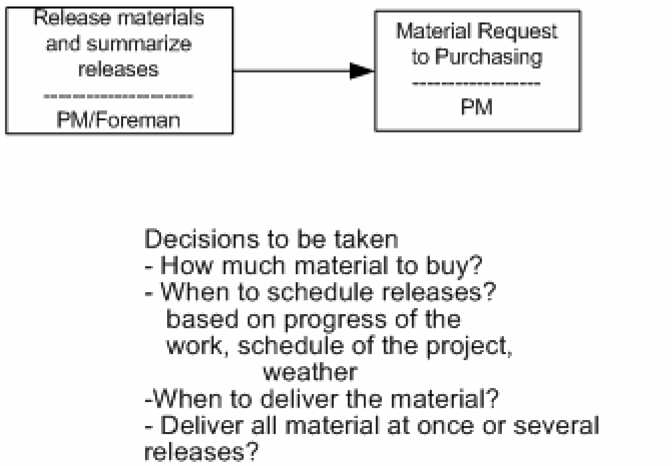

Figure 1.3: Decision Node for Material Ordering

Once the decision nodes were identified, knowledge-management concepts were applied to design an integrated, effective system of decision-support tools for the material supply chain of the electrical contractor. The design specifies a knowledge database and procedures that allows a contractor to perform what-if scenarios on various procurement decisions to identify better alternatives. Furthermore, this design could serve as a “road map” for the development and integration of decision support tools by a contractor. The system design focus mainly on decisions concerned with material procurement, delivery options, and storage alternatives. However, other decision making areas were studied and the effects of these decision making activities in procurement, delivery and storage options were considered. Therefore, an integrated approach was used to improve communication and minimize information flow gaps between all the parties and departments involved. Furthermore, it was investigated if the procurement, delivery and storage options could be studied in isolation from the other decision making activities.

Decision-modeling techniques were used to develop an integrated system of decision support for material procurement for the electrical contractor. A computer program or algorithm that performs the calculation of performance measures for each alternative is called a descriptive model because it only describes a cause-effect relationship without making any judgment about the desirability of each alternative. This judgment is left to the decision maker. The decision model at any decision node is as depicted in Figure 1.4. The factors (or parameters) and alternatives define the inputs. Performance measures define the output. Alternatives represent the different options available for a particular decision node. Parameters represent "values" that could restrict the decision making process. Performance measures are used to measure the effectiveness of the system with the alternatives and parameters used as inputs.

Figure 1.4 is a schematic representation of the decision model for choosing the order quantity of an item that illustrates how such a computer program would be designed. Some decision models go further than describing the outcomes of each alternative by determining the better choice from among all of the alternatives. These kinds of models are called prescriptive models and embody a search routine that a computer uses to carry out an intelligent, restricted trial-and-error search for the better solution. Prescriptive models leverage the decision maker by evaluating tradeoffs that are too complex or numerous for human judgment to comprehend.

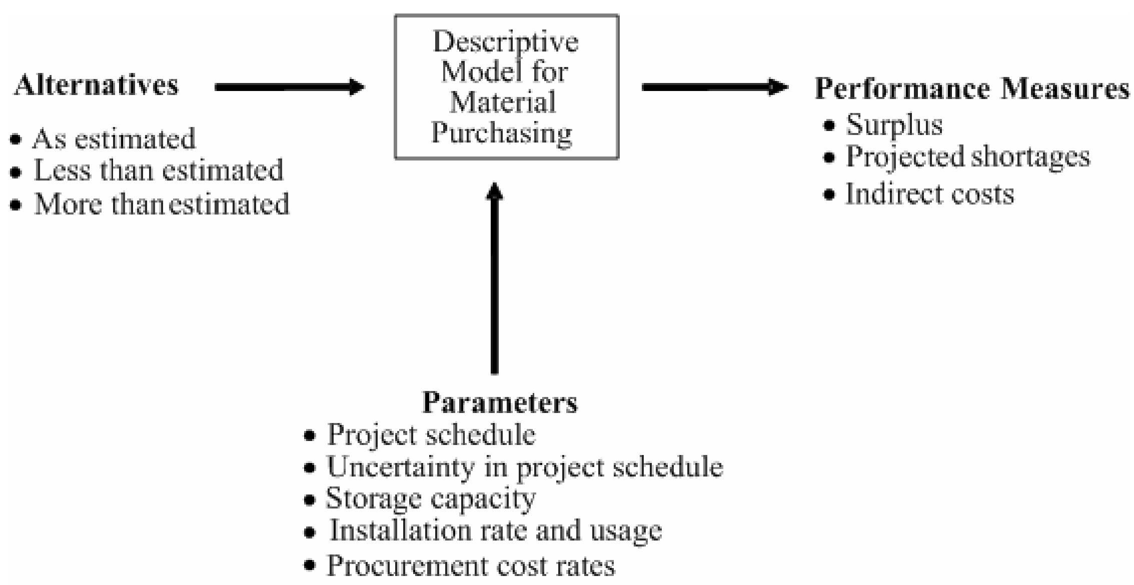

Figure 1.4: Framework for Decision Models

For example, a descriptive model could be used when a company orders materials. Decision alternatives might include the time when an order should be placed, resources needed, where to deliver, how much to order, among others. Examples of parameters might include the storage capacity, availability of space, location of the job, among others. Examples of performance measures might include lateness, earliness, surplus of storage capacities, costs, among others. Based on the information input (i.e. alternatives and the parameters), an analysis will be performed to assist the electrical contractor in that decision. In this case, the model will help the decision maker by suggesting where the material should be stored. This is only one example of how the model could be used. Other applications such as batch order size, safety stock inventory and sourcing models could be analyzed with the model. The challenge is to consider all the elements that could have an impact in the specific decision to be made and provide not only the most cost effective solution, but the solution that could better serve the electrical contractor needs at that particular instant.

The next task was to define all of the knowledge elements that constitute the alternatives, factors or parameters and performance measures for each decision node. This required identifying all the data that is needed to make decisions and any other information that might impact the way in which a decision is taken for a particular decision node. The challenge lies in discerning the data that could be used and considered as knowledge from the vast amount of data that could be available.

A database of all the alternatives and parameters needed, for every decision node to be considered, needs to be established. The challenge is to consider all the elements that could have an impact in the specific decision to be made and provide not only the most cost effective solution, but the solution that could better serve the EC needs at that particular instant. A definition of the data, models, decision makers and procedures that make up the knowledge and a mapping of their relationships and uses is a vital first task towards building integrated decision support for the contractor. The term “knowledge management” has become the recognized name for this definition and structuring of all of these “knowledge elements” that an organization uses to make decisions. Understanding the knowledge is the first step to manage it effectively and to document it. For our purpose, the management of the knowledge requires defining the elements and the decision rules associated with every particular decision. In other words, the alternatives and parameters considered to make decisions at every decision node need to be clearly defined. This process needs to be done for every decision node that will be considered in the study.

Table 1.1 presents the procurement decisions to be made, the alternatives and parameters that affect these decisions and the performance measures associated with each decision.

Decision	Alternatives	Parameters	Performance Measures
What material to buy?	• Major material • Commodities • Consumables	• Schedule • Foreman • Production and usage • Needed vs. wanted	• On site availability
When to buy material?	• 3 months in advance • 1 month in advance • 1 week in advance • 1 day in advance • Same day	• Type of material (commodity vs. major) • Storage Capacity • Location of the project • Location of the supplier • Criticality of the material • Order to install vs. order to pre-fab • Supplier's performance and ability to meet schedules	• lateness • earliness • direct costs • indirect costs
Where to buy material?	• Local supplier • Non-local supplier • Vendor Managed Inventory	• Arrangements with suppliers • Availability • Criticality • Location of supplier • Location of project • Supplier's performance • Discounts	• Lateness • Earliness • Quality • Quantities
How Much to order?	• As estimated • Less than estimated • More than estimated	• storage capacity • installation rate and usage • costs • discounts	• surplus • shortages

Where to deliver?	• Jobsite • Warehouse/Pre-fab shop • Subcontractor	• Storage capacity • Immediate installation vs. critical item not be installed immediately • To be used in pre-fab or not • Costs • Location of the project • Location of the warehouse	• Availability when needed • Quality • Quantity • Costs
Where on site to store?	• “Sea cans” • on floor inside the building	• on-floor space available • schedule	• loss • theft • damage • re-handling

Table 1.1: Procurement Decisions, Alternatives, Parameters and Performance Measures

The identification of these data required visits and interviews to electrical contractors. These visits allowed identifying the alternatives and parameters considered by these electrical contractors. These knowledge elements not only included what the common literature identifies, but, in addition, parameters that are particularly important for every company individually were identified. Interview sessions allowed for clearly defining the alternatives and parameters that they consider, collect these alternatives and parameters, analyze those ideas and incorporate them into the database of knowledge elements needed as inputs for the development of the model.

The relationships among the alternatives, parameters and performance measures needed to be defined. These relationships are described graphically by developing flowcharts that will illustrate the relationships among the different elements (i.e. alternatives, parameters and performance measures). This representation clearly establishes these relationships to allow users to clearly follow the way in which the decision support system works. These flowcharts are further discussed and explain in Chapter 7. In addition, feedback from the electrical contractors was important to set up the structure of the knowledge management database.

Once the descriptive models for the decision making process and the data needed were identified, flowcharts that describe the material management decision making process were developed. These flowcharts describe in detail the decision making process and the parameters that could have an effect in the decision to be taken. These flowcharts are presented and described in Chapter 7. A system for classifying the parameters needed in the decision making process was also developed. The system known as SPARCS is presented in Chapter 8.

It is important to clarify that the research does not aim to develop an information system for decision making. The research will rather look at the decisions to be made and the relationship that might exist among decisions, data and decision makers.

1.7 Industry Relevance

All sectors of the construction industry share a common ground for material management and control. Thus, the discussion presented although it is directed towards the electrical contracting industry could be applied to any sector. Material management activities are required throughout a construction project and in every construction project. Moreover, the success of the project is highly dependent on the successful management of the materials required. Hence, managing the materials in an effective way is very critical to all parties involved not only in the construction industry but also in other industries.

The research work is expected to provide the following benefits to the industry:

- Improve the management of materials for the electrical contracting industry
- Provide guidelines to assist in the materials management learning process
- Standardization of the material management practices within a company
- Investigate state of the art tools and technologies that could be helpful in managing and monitoring material and control its quality.
- With the development of a structure for a material management decision support system, facilitated through a knowledge management database, the following benefits are expected:
    - minimization of the repetition of past failures
    - sharing of successful experiences
    - learn from other people’s experiences to avoid pitfalls and to minimize the repetitions of errors

- identify specific design, process, or decision that reduces or eliminates the potential for failures
- availability of corrective actions for typical problems that might impact the cost of a project

1.8 Scope and Limitations

The proposed research will be limited to the following assumptions:

- The research will only address or consider the electrical contracting industry.
- The research will not study the decision making process for the entire material management process as it will focus in the decision making process for material procurement (purchasing, delivery options and storage alternatives).
- The research will be focused on medium size contractors that specialize in commercial construction and it will most likely consider procurement for a single project instead of procurement and aggregation for multiple projects.
- The research will intend to design a blueprint for a knowledge management system for supply chain and not the development of a computer application
- The research will not consider implementation of the model in the electrical contracting industry.

1.9 Dissertation Overview

Chapter 1 presented the research statement. This chapter presented a description of the problem statement, the objective of the research, the justification for the research, the methodology for the research work, relevance of this work to the construction industry and the limitations of this study. Chapter 2 presents a general introduction to material management in construction. This chapter defines what a material management system is, typical materials used in the construction industry, why is important to have a material management system and the advantages of having it. Chapter 3 presents the current state of knowledge in material management for construction. This chapter describes other research efforts that have been performed in material management for construction. These studies have been classified into materials management and project management, benefits and costs of a materials management system, role of vendor/supplier and fabricator, models developed and studies of effectiveness of materials management, use of technology for materials management, other research related to materials management, materials management for the electrical contracting industry, cultural change in construction, supply chain management for the manufacturing industry, and knowledge management. Chapter 4 presents an overview of the electrical contracting industry including services provided by electrical contractors, materials purchasing by electrical contractors, and typical products used by electrical contractors. In addition, this chapter describes the current material management practices in the electrical contracting industry including current materials management practices in the electrical contracting industry the different phases: bidding, sourcing, material procurement, construction and post-construction. This chapter also describes supplier/contractor arrangements such as partnering, among others. Chapter 5 describes the many challenges that are encountered during the five phases of the materials management process. These challenges were grouped into three categories: information technology, decision modeling and implementation management. Chapter 6 presents the decision modeling approach used in the study. The chapter gives an introduction to decision modeling, describes the modeling approach used and explains the decision making processes studied. Chapter 7 presents the framework for a Decision Support System (DSS) for supply chain management. The chapter provides a description of the decision making process for material supply chain for the decision nodes considered: what material to buy decision node, how much to order decision node, when to buy material decision node, when to deliver material decision node, where to deliver material decision node, where to store on site decision node. In addition, the chapter provides a description of framework for decision models. Chapter 8 provides a description of SPARCS - Supply-chain PARameters Classification System. The chapter describes the development of SPARCS, the data definition for SPARCS, and the application of SPARCS to all the decisions considered in the study. Chapter 9 presents an example application of the framework and how it could be used to decide the source for material supply. The example presented is fairly comprehensive and describes in detail how the model would work once implemented in a computer application. Chapter 10 presents a summary of the work, the conclusions of this work, contributions and directions for future research. Appendix A presents the questionnaires used in the interviews. Appendix B presents the flowcharts for the material management process for the companies interviewed and the narratives for the flowcharts.

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CHAPTER TWO: INTRODUCTION TO MATERIALS MANAGEMENT

Construction materials constitute a major cost component on any construction project. The total cost of installed materials (or *Value of Materials*) may be 50% or more of the total cost (Stukhart 1995, Bernold and Treseler 1991), even though the factory cost may be a minor part of the total, probably less than 20-30%. This is because the manufactured item must be stored, transported, and restored before it is put in place or "consumed" at the site. The total cost of materials will include, in addition to the manufacturer selling cost, the cost of procurement (cost of placing processing and paying the material, physical distribution, the distributor's cost, and the transportation of materials), and the site-handling costs (cost of receiving, storage, issuing, and disposal). The efficient procurement and handling of material represent a key role in the successful completion of the work. It is important for the contractor to consider that there may be significant difference in the date that the material was requested or date when the purchase order was made, and the time at which the material will be delivered. These delays can occur if the contractor needs a large quantity of material that the supplier is not able to produce at that time or by any other factors beyond his control. The contractor should always consider that procurement of materials is a potential cause for delay (Willis, 1986).

Poor planning and control of materials, lack of materials when needed, poor identification of materials, re-handling and inadequate storage cause losses in labor productivity and overall delays that can indirectly increase total project costs. Effective management of materials can reduce these costs and contribute significantly to the success of the project.

2.1 Background

The Webster's dictionary defines materials as "*the elements, constituents, or substances of which something is composed or can be made.*" Ballot (1971) defines materials as the physical materials that are purchased and used to produce the final product and does not suggest that materials are the final product. In other words, materials are the parts used to produce the final product. Bailey and Farmer (1982) define materials as the goods purchased from sources out of the organization that are used to produce finished products. Stukhart (1995) defines materials as the items that are used to produce a product and which include raw materials, parts, supplies and equipment items.

Dobler and Burt (1996) classify manufacturing materials into five categories. These categories are:

- Raw materials- materials that the company converts into processed parts. This might include parts specifically produced for the company and parts bought directly off the shelf (i.e. bolts, nuts).
- Purchased parts- parts that the company buys from outside sources (i.e. rubber parts, plastic parts).
- Manufactured parts- parts built by the company (i.e. tower case for a computer)
- Work in process- these are semi-finished products found at various stages in the production process (i.e. assembled motherboard).
- MRO supplies- maintenance, repairing, and operating supplies used in the manufacturing process but are not part of the final products (i.e. soap, lubricating oil).

Chandler (1978) states that construction materials can be classified into different categories depending on their fabrication and in the way that they can be handled on site. He classifies the materials into five categories. These categories are:

- Bulk materials- these are materials that are delivered in mass and are deposited in a container.
- Bagged materials- these are materials delivered in bags for ease of handling and controlled use.
- Palleted materials- these are bagged materials that are placed in pallets for delivery.
- Packaged materials- these are materials that are packaged together to prevent damage during transportation and deterioration when they are stored.
- Loose materials- these are materials that are partially fabricated and that should be handled individually.

Table 2.1 presents some examples of commonly used materials in construction and their classification.

Material	Bulk	Bagged	Palleted	Packaged	Loose
Sand	x				
Gravel	x				
Topsoil	x				
Paving Slabs					x
StructuralTimber					x
Cement	x	x	x		
Concrete	x				
Pipes				x	x
Tiles				x	
Doors			x		
Electrical Fittings				x	

Table 2.1: Classification of Materials (Adopted from Chandler, 1978)

Stukhart (1995) states that the main categories of materials encountered in a construction project are engineered materials, bulk materials, and fabricated materials.

- Bulk materials- these are materials manufactured to standards and are purchased in quantity. They are bought in standard length or lot quantities. Examples of such materials include pipes, wiring, and cables. They are more difficult to plan because of uncertainty in quantities needed.
- Engineered materials- these materials are specifically fabricated for a particular project or are manufactured to an industry specification in a shop away from the site. These materials are used for a particular purpose. This includes materials that require detailed engineering data.
- Fabricated materials- these are materials that are assembled together to form a finished part or a more complicated part. Examples of such materials include steel beams with holes and beam seats.

Importance of Materials for a Project

Problems related to managing the flow of materials can be found in every organization. The efficient management of materials plays a key role in the successful completion of a project. The control of materials is a very important and vital subject for every company and should be handled effectively for the successful completion of a project. Materials account for a big part of products and project costs. The cost represented by materials fluctuates and may comprise between 20–50% of the total project cost and sometimes more. Some studies concluded that materials account for around 50-60% of the project cost (Stukhart, 1995 and Bernold and Treseler, 1991). Materials are critical in the operations in every industry since unavailability of materials can stop production. In addition, unavailability of materials when needed can affect productivity, cause delays and possible suspension of activities until the required material is available. It is important for a company to consider that even for standard materials, there may be significant difference in the date that the material was requested or date when the purchase order was made, and the time in which the material will be delivered. These delays can occur if the quantities needed are large and the supplier is not able to produce those materials at that time or by any other factors beyond the control of the company. The company should always consider that purchase of materials is a potential cause for delay (Willis, 1986). Unavailability of materials is not the only aspect that can cause problems. Excessive quantities of materials could also create serious problems to managers. Storage of materials can increase the costs of production and the total cost of any project. When there are limited areas available for storage, the managers have to find other alternatives to store the materials until they are needed. Some of these alternatives might require re-handling of materials, which will increase the costs associated with them. Provisions should be taken to handle and store the materials adequately when they are received. Special attention should be given to the flow of materials once they are procured from suppliers.

It is obvious that materials should be obtained at the lowest cost possible to provide savings to the company (Damodara, 1999). In the late 1970's, construction companies experienced an increase in costs and a decrease in productivity. Owners of these companies thought that these increases in cost were due to inflation and economic problems. Further research concluded that these companies were not using their resources efficiently and that the decrease in productivity was also attributable to poor management (Stukhart, 1995). Material management has been an issue of concern in the construction industry. 40% of the time lost on site can be attributed to bad management, lack of materials when needed, poor identification of materials and inadequate storage (Baldwin et. all, 1994).

The need for an effective materials planning system becomes mandatory. Some companies have increased the efficiency of their activities in order to remain competitive and secure future work. Many other firms have reduced overheads and undertaken productivity improvement strategies. Considerable improvement and cost savings would seem possible through enhanced materials management. Timely availability of materials, systems, and assemblies are vital to successful construction. Materials management functions are often performed on a fragmented basis with minimal communication and no clearly established responsibilities assigned to the owner, engineer or contractor. Better material management practices could increase efficiency in operations and reduce overall cost. Top management is paying more attention to material management because of material shortages, high interest rates, rising prices of materials, and competition. There is a growing awareness in the construction industry that material management needs to be addressed as a comprehensive integrated management activity.

What is material management?

Different researchers provide different definitions for material management, therefore different definitions can be found in different references. Basically, material management is concerned with the planning, identification, procuring, storage, receiving and distribution of materials. The purpose of material management is to assure that the right materials are in the right place, in the right quantities when needed. The responsibility of one department (i.e. material management department) for the flow of materials from the time the materials are ordered, received, and stored until they are used is the basis of material management.

- Ballot (1971) defines material management as the process of planning, acquiring, storing, moving, and controlling materials to effectively use facilities, personnel, resources and capital.
- Tersine and Campbell (1977) define material management as the process to provide the right materials at the right place at the right time in order to maintain a desired level of production at minimum cost. The purpose of material management is to control the flow of materials effectively.
- Beekman-Love (1978) states that a material management structure should be organized in such a way that it allows for integral planning and coordination of the flow of materials, in order to use the resources in an optimal way and to minimize costs.

- Chandler (1978) states that material management systems should be implemented to plan, order, check deliveries, warehousing, controlling the use of materials, and paying for materials. He adds that these activities should be interrelated.
- Ammer (1980) defines material management as the process in which a company acquires the materials that it needs to achieve their objectives. This process usually begins with the requisition of materials from the supplier until the material is used or incorporated into a product.
- Bailey and Farmer (1982) define material management as a concept concerned with the management of materials until the materials have been used and converted into the final product. Activities include cooperation with designers, purchasing, receiving, storage, quality control, inventory control, and material control.
- Gossom (1983) indicates that a material management system should have standard procedures for planning, expediting, transportation, receipt, and storage to ensure and efficient system for materials control.
- Cavinato (1984) states that material management involves the control of the flow of goods in a firm. It is the combination of purchasing with production, distribution, marketing and finance.
- Arnold (1991) states that material management is a function responsible for planning and controlling of materials flow. He adds that a materials manager should maximize the use of resources of the company.
- Stukhart (1995) defines material management as the activities involved to plan, control, purchase, expedite, transport, storage, and issue in order to achieve an efficient flow of materials and that the required materials are bought in the required quantities, at the required time, with the required quality and at an acceptable price.
- Plemmons and Bell (1995) define material management as the plan and control of all activities to ensure the correct quality and quantity of materials and equipment to be installed are specified in timely manner, obtained at reasonable cost and are available when needed.
- Dobler and Burt (1996) state that material management is designed to improve the activities related to the flow of materials. They add that material management should

coordinate purchasing, inventory control, receiving, warehousing, materials handling, planning, and transportation.

The role that a materials manager plays in an organization is strictly economical since the materials manager should keep the total cost of materials as low as possible. The person in charge of handling materials should keep in mind the goals of the company and insure that the company is not paying extra money for materials. The goal of every company is to make a profit. This is the basis for company survival, costs should not exceed income, but keeping in mind customer's expectations.

The typical tasks associated with a material management system are (Tersine and Campbell (1977), Ammer (1980), Stukhart (1995)):

- Procurement and purchasing
- Expediting
- Materials planning
- Materials handling
- Distribution
- Cost control
- Inventory management / Receiving/ Warehousing
- Transportation

Purchasing and procurement deals with the acquisition of materials to be used in the operations. The primary function of purchasing and procurement is to get the materials at the lowest cost possible, but keeping in mind quality requirements. Expediting is the continuous monitoring of suppliers to ensure on time deliveries of materials purchased. The purpose of materials planning is to procure the materials for the dates when they are needed, storage facilities, and handling requirements. The primary function of materials handling is to manage the flow of materials in the organization. The manager has to assure that the costs associated with handling materials are kept to a minimum. In cost control, the manager has to insure that the costs to buy materials are kept to a minimum. In other words, the manager has to insure that he is buying the products at the lowest possible price. The inventory management deals with the availability of materials.

Transportation involves using the safest most economical means to transport the materials to the site where they are needed.

Figure 2.1 depicts the different phases of the material management process including the relationship and interdependency between the different activities in each phase. From this figure it can be seen that decisions taken at each phase in the system, directly affect the activities of the phases that follow.

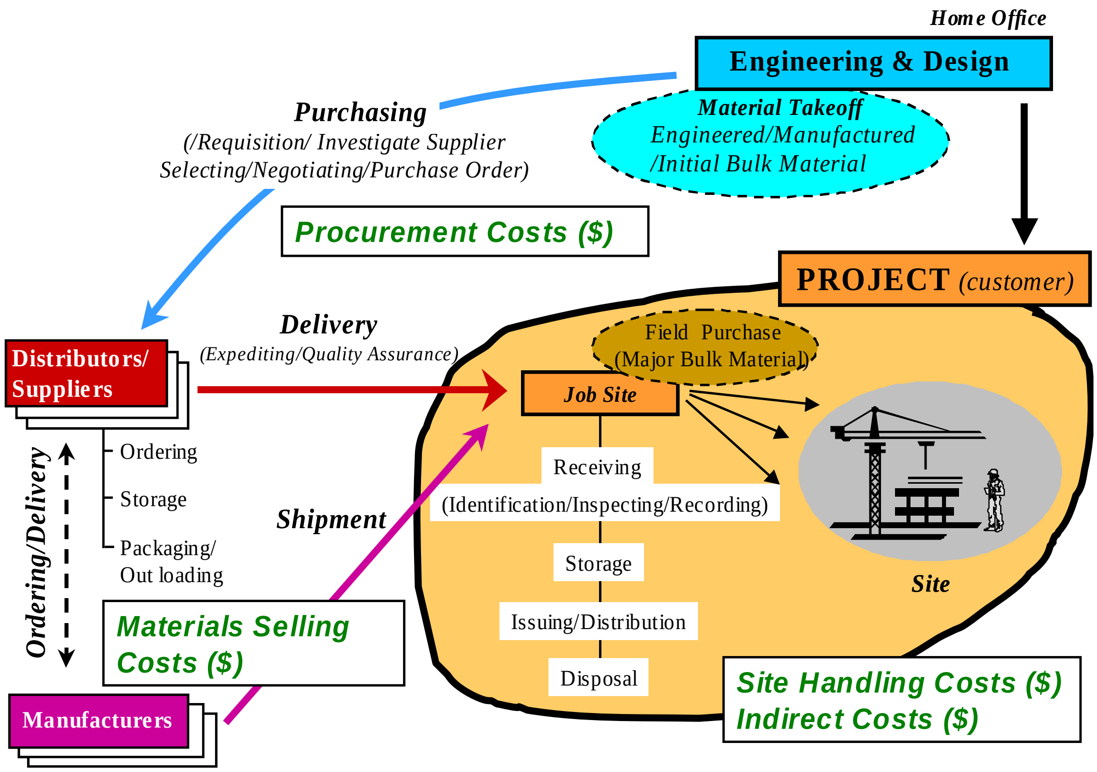

Figure 2.1: Typical Material Management in Construction (Source: Thabet, 2001)

As a result, a successful implementation of a material management system needs to consider the different decisions made at various phases of the supply chain.

2.2 Need for Material Management Systems

The costs associated with material management are hidden in other activities or included as overhead costs. Stukhart (1995) states that studies from the Construction Industry Cost Effectiveness Project (CICEP) concluded that senior management have not recognized the contribution of material management to cost issues in projects, that personnel involved in material management activities do not receive an adequate training, and that the computer systems used by companies are not good sources of information for materials control. Historically managers had paid more attention to the costs associated with personnel, equipment and plant and little attention has been given to materials. For manufacturing organizations, the costs related to materials have increased and had become the largest expenditure of the organization; therefore more attention has been placed into activities related to materials (Tersine, 1978). The cost of materials has escalated to twice the cost of labor between 1975 and 1980 inducing companies to pay more attention to activities related to materials (Bernold and Treseler, 1991).

Traditionally the responsibilities for activities related to materials flow have been divided between different departments. Figure 2.2 depicts the division of responsibilities for material management. The activities related to material management are divided between different departments. For example, the finance department is in charge of the purchasing activities while the manufacturing department is in charge of the control of materials during production. This division of responsibilities makes it difficult to coordinate the activities related to materials. In addition, this division can make the control and identification of materials extremely difficult.

The integration of the functions related to materials into a single department makes it easier to control and identify all the activities related to material flow and costs. Figure 2.3 depicts the integrated approach for material management. Material management is designed to coordinate and control the materials needed and activities related to those materials. In a typical organization, the material activities are interrelated (Dobler and Burt, 1996).

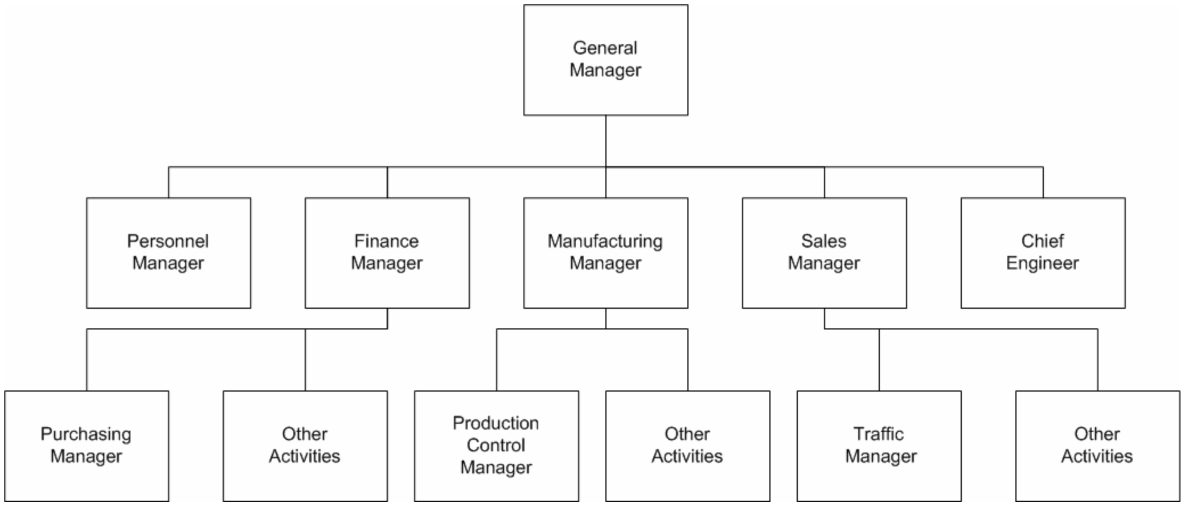

Figure 2.2: Division of responsibilities for material management (Adopted from Ammer, 1981)

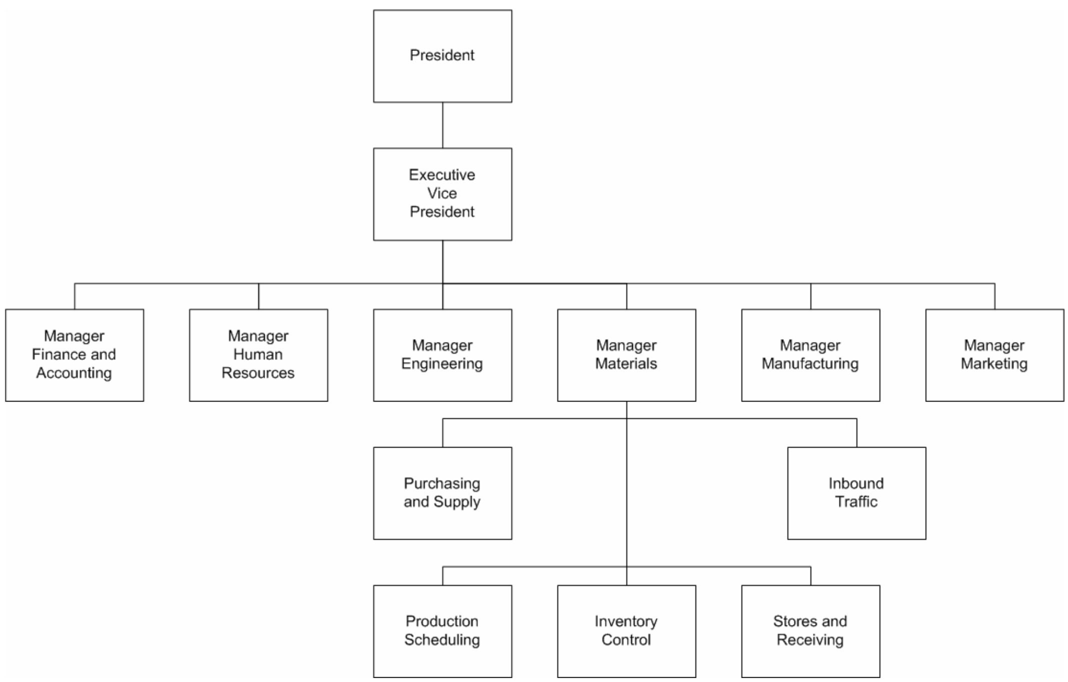

Figure 2.3: General Structure of a Material management System in a Company (Adopted from Dobler and Burt, 1996)

Figure 2.4 illustrates a typical flow of materials, and material activities in an organization. From the figure, it can be seen that decisions taken at early stages in the material management flow might affect other activities and decisions to be made in later stages. For example, if the proposals from suppliers are not analyzed (i.e. step 6 in the purchasing activities), then the selection of suppliers might be affected (i.e. step 3 in the supply management activities).

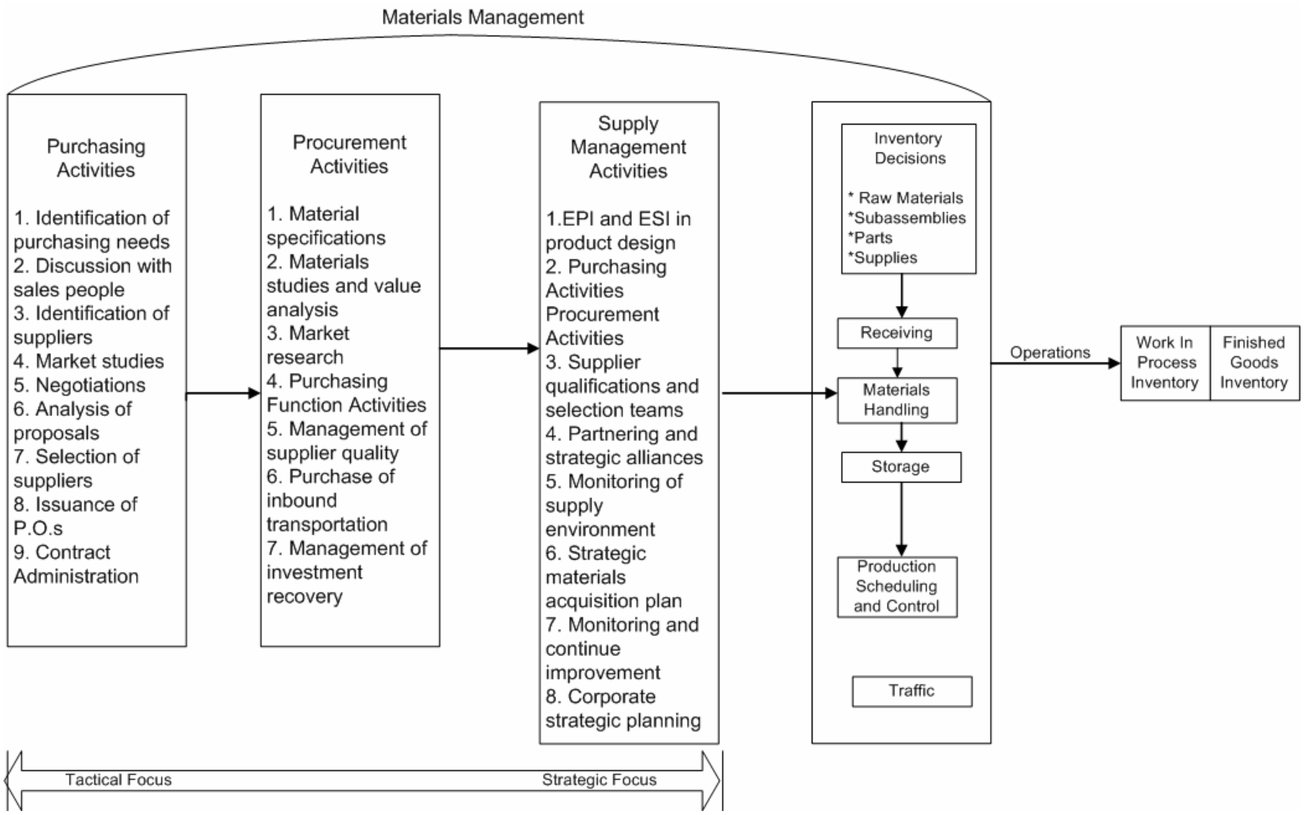

Figure 2.4: Relationship of Purchasing/Procurement/Supply management with Material management (Adopted from Dobler and Burt, 1996)

Coordination is needed in order to reduce the impact that a decision at a certain stage might have in other activities. Communication is essential among members of the team to avoid conflicts and to take the better decisions regarding materials flow.

2.3 Goals of Material management

As was mentioned previously, the role of the materials manager is strictly economical within an organization. This section will describe some of the aspects that the materials manager should keep in mind to handle all activities related to materials appropriately. Cavinato (1984) states that the objectives of a material management system should include lowest final cost, optimum quality, assurance of supply, and lowest administrative costs. The materials manager should obtain the materials needed at the lowest cost possible. By buying products at the lowest possible costs, operating costs can be reduced and profits can be increased. Proper handling and storage of materials can reduce the total cost of materials; therefore the materials manager should ensure that materials are handled properly and stored in the most adequate places. Quality is a very important aspect that the materials manager has to keep in mind. When specifications require a high quality product, quality could become the most important objective. Suppliers play an important role in any organization. Many companies rely greatly in outside suppliers for the materials needed for production. Good relations with suppliers might be decisive for a company to be in business. Companies that have good relations with suppliers could be more successful in attracting customers than companies that have bad relations with suppliers. When a company has good relations with its suppliers it could benefit from cost reductions, cooperative environment from the employees of the supplier, and willingness to help with materials ordered and orders pending. When a company has bad relation with their suppliers it might be possible that it experiences late deliveries or wrong materials delivered. This will have an impact in the total cost of the product, possibly increasing the total costs, and delaying the completion of the final product. Materials acquisition from the procurement time until it is received in the field can have a significant impact on the schedule of a construction project. Based on the studies presented, it is clear that effective management of materials can minimize the impact that lack of materials or improper management of materials could have in the overall schedule and cost of the project. The materials manager should assure that effective and economical transportation are used to transport materials to the site.

2.4 Benefits of Material Management

An effective material management system can bring many benefits for a company. Previous studies by the Construction Industry Institute (CII) concluded that labor productivity could be improved by six percent and can produce 4-6% in additional savings (Bernold and Treseler, 1991). Among these benefits are:

- Reducing the overall costs of materials
- Better handling of materials
- Reduction in duplicated orders
- Materials will be on site when needed and in the quantities required

- Improvements in labor productivity
- Improvements in project schedule
- Quality control
- Better field material control
- Better relations with suppliers
- Reduce of materials surplus
- Reduce storage of materials on site
- Labor savings
- Stock reduction
- Purchase savings
- Better cash flow management

This chapter provided an introduction to material management and the benefits that could be realized by having an effective material management system. The basic knowledge needed to understand the basis of the research and why it is important to undertake this research work was presented. The next chapter will present the current state of knowledge in material management, particularly for the construction industry. In addition, areas related to material management that are particularly important for this research work, such as cultural change and knowledge management, are also described.

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CHAPTER THREE: CURRENT STATE OF KNOWLEDGE IN MATERIAL MANAGEMENT FOR CONSTRUCTION

A successful construction company meets the customer's needs effectively and in the process makes a profit. Owners are looking for construction companies that can deliver the project at low cost, with the required standards of quality and in a reasonable time. Similar to other industries, the cost of materials in construction accounts for a considerable part of the project cost. Some studies concluded that materials account for around 50-60% of the project cost (Stukhart (1995), Bernold and Treseler (1991)). It is obvious that materials should be obtained at the lowest cost possible to provide savings to the company (Damodara, 1999). In the late 1970's, construction companies experienced an increase in costs and a decrease in productivity. Owners of these companies thought that these increases in cost were due to inflation and economy problems. Further research concluded that these companies were not using their resources efficiently and that the decrease in productivity was also attributable to poor management (Stukhart, 1995). Materials management has been an issue of concern in the construction industry. In addition, 40% of the time lost on site can be attributed to bad management, lack of materials when needed, poor identification of materials and inadequate storage (Baldwin et. all, 1994).

In any construction project the cost of materials can exceed half the cost of construction. Many researches have indicated that in a typical industrial facility 50% to 60% of the total cost is for equipment and materials. The proportion in terms of cost of materials has increased more than labor. Bernold and Treseler (1991) stated that cost of materials escalated twice the cost of labor between 1975 and 1980 and 60% of costs of projects were materials and equipment. They also pointed out that the construction industry spends 0.15% in material management systems.

Some studies have shown that an effective material management system can produce 6% improvement in labor productivity and a computerized system can produce additional 4-6% in savings (Stukhart, 1995). There is a growing awareness in the industrial construction industry that materials management needs to be addressed as a comprehensive integrated management activity. Researchers have acknowledged the importance of materials and the impact that these have in the total project cost, plans and operations. This chapter presents an overview of some of the aspects considered in previous and ongoing research in materials management in construction.

3.1 Materials Management and Project Management

Different authors define the concept of materials management in different ways. However, all the researchers point out that materials management is extremely important for a successful project completion. The basic idea behind materials management is that the materials and/or equipment needed, in the quantities needed, meeting the standards of quality specified, are obtained at a reasonable cost and are available when needed on the construction site. The process of materials management should integrate purchasing, expediting, and inventory control. The benefits of implementing a materials management system have not been recognized by senior management. A well managed materials management system can contribute to the cost effectiveness of a project. In order for a company to implement a successful materials management system, top management support is required.

Damodara (1999) identifies seven stages in which the project management team must ensure a materials management focus. These seven stages are: Planning, Preliminary design, Final design, Procurement, Vendor control, Construction, and Closeout. A description on the tasks of managers in each stage follows.

In the Planning stage the project management team develops the materials management team and the functional relationships among members of the team in order to develop a team that is united and working towards the same goal. In this stage the materials management focus should be defined and adapted to the mission, which is to complete the project at the lowest cost possible. In the Preliminary design phase the materials to be used in the project are defined. This definition of materials should minimize the cost of the design, but assuring that the materials and equipment selected meet the owner's requirements. Once materials are defined, the project team starts to inquire suppliers for information about the materials needed and possible delivery dates.

In the Final design stage the team should develop specifications for equipment and materials to be used in order to request and obtain competitive proposals. In the Procurement stage the team should consider to use standard materials that meet the specifications and requirements. In addition, the submittals should be kept to minimum levels. This might ensure more reliable delivery dates. The team should not buy materials advance. Buying materials earlier than needed may require re-handling which will increase costs. When dealing with vendors, the team should review the drawings submitted by the vendor without delay, this will eliminate delays due to necessary changes. In addition, the team has to put in place a plan to expedite the orders so that the materials are delivered according to the schedule. In the Construction stage the team should account for all materials and equipment received. This practice will be useful to avoid duplicated orders. These materials and equipment should be available when needed on site to avoid delays. In the Closeout stage the project team should dispose any surplus materials. The disposal process can be simplified if the team uses standard materials. The team can identify any pitfalls in the materials management process and identify areas of improvement. The success of a project depends greatly in the effective implementation of materials management system.

3.2 Benefits and Costs of a Materials Management System

The Construction Industry Institute (CII) created a materials management task force in the middle 1980s. This task force was comprised by owners, contractor and people from the academy. The first research conducted was to examine the attributes of a materials management system. Bell and Stukhart (1986) presented the attributes of a materials management system that they identified as part of a research work. The attributes identified were: Planning and communications, Material takeoff and engineering interface, Vendor Inquiry and Evaluation, Purchasing, Expediting and Shipping, Warehousing, receiving, and material distribution, Material control, and Computer Systems

Bell and Stukhart (1986) completed another study to identify the costs and benefits of a materials management system. They stated that the development of some materials management systems that combine takeoff, expediting, purchasing, and vendor evaluation, among other factors, can produce benefits in productivity, cash flow and reductions in inventory. The benefits identified by Bell and Stukhart are:

- Improved labor productivity
- Reduced Bulk Materials Surplus
- Reduced Materials Management Manpower
- Improved Vendor Performance
- Other benefits
    - Timely materials procurement results in reduced requirement for physical warehouse facilities
    - Other benefits are those associated with timely material purchases

Some of the factors that might impact the benefits of a materials management system were also identified. Among these factors, inadequate training, inadequate, insecure, or poorly designed warehouse and laydown areas are included.

Wong and Norman (1997) stated that benefits of implementing materials planning software packages in the manufacturing industry include labor savings, stock reduction, purchase savings and better cash flow management. They suggested implementing a construction materials planning system (CMPS) to determine what components are needed. In addition, it should help to determine what to order, order quantity, ordering time, when to schedule delivery. They identified the major costs such as acquisition cost, start-up costs and annual operating costs. Benefits identified include labor savings, stock savings, cost control savings, purchase savings, earnings generated from extra contracts

Tuffour (1987) performed some research in materials management for construction in developing countries. He identified the following as benefits of a materials management system and these include the following: reduction in paper work, coordination or cooperation among departments, improvement in relations with suppliers, reduction in double handling of materials, assurance of materials availability, and increase in productivity at the job site.

In addition, Tuffour identified the following as costs associated with the development of a materials management system:

- Warehousing

- Personnel
- Computer system development and application

3.3 Role of Vendor/Supplier and Fabricator

The relationship between the contractor and suppliers is crucial for the success of a project and it is vital in determining whether or not a construction company stays in business. If the contractor has a good relationship with the suppliers, better prices and more reliable delivery dates can be expected. On the other hand, if the relationship with the supplier is not a good one, the contractor can expect higher prices and late deliveries. This section will examine the effects that the fabricator and/or vendor might have in a project as stated by previous research.

Thomas and Sanvido (2000) stated that although fabricators are a critical component for material management process, their role has not been considered in previous research. Furthermore, they pointed out that they didn’t find quantitative research studies that studied the impacts in a project due fabricator‘s performance. They analyzed three case studies to demonstrate the quantitative effect of the fabricator in labor productivity.

Agapiou, et. al. (1998) investigated the role of merchants/suppliers in the supply process and discussed the changes in their roles. They stated that a supply chain can bring savings in the costs of materials and components and that the supply includes price, discounts, reliability and timing of deliveries, credit facilities for payment.

Bernold and Treseler (1991) stated that the performance of suppliers is related to the success of the material management system, thus selection of vendors is a very important aspect. The introduced the Concept of Best Buy. Best Buy assumes certain level of suitability, but considers cost and procurability, transportation and disposal. Best Buy not necessarily means best price, procurement and technical specifications should also be considered. In addition, other factors such as specifications, price, delivery time, etc. should be considered.

3.4 Models Developed and Studies of Effectiveness of Materials Management

The delivery of materials to a construction site is a critical aspect. The supply of building materials and components is filled with obstacles that can have a significant effect on levels of productivity if the materials are not available when needed. Therefore, the delivery of materials is an aspect which demands the introduction of a carefully developed system to monitor and control the problems as early as possible. In addition, the conditions in which the materials are kept on site could lead to damage from weather and movement of people, plant and equipment. This aspect could also have an impact in productivity.

Agapiou, et. al. (1998) studied the role of logistics in the materials flow process. They defined logistics as the art of moving, lodging and supplying troops and equipment. For the construction industry, logistics comprise planning, organization, coordination, and control of the materials flow from the extraction of raw materials to the incorporation into the finished building. Logistics spans the organization, from the management of raw materials through to the delivery of the final product. They concluded that the success of the model was based on an integrated approach and the roles adopted by the participants during design and construction phases. In addition, they concluded that the primary focus of logistics is to improve communication and coordination between participants during design and construction, particularly in the materials flow control. They stated that Partnering arrangements could lead to effective materials control through coordination and cooperation.

Proverbs, et. al. (1995) examined the materials management procedures and wastage levels of a medium sized building contractor during the recession in UK. Some comparisons are made with wastage levels prior to recession to evaluate improvements in materials control procedures. They prepared a structured questionnaire based on materials management practices and distributed to site managers. Actual site measurement of direct materials wastage was undertaken. The research team concluded that a materials manager could reduce wastage, improve materials control on site and lead to overall improvements in the competitiveness and efficiency of a company. If the site management is motivated, the morale of employees will increase which will increase the percent of time spent doing productive work.

Formoso and Revelo (1996) developed a method for improving the materials supply system in small sized building firms using total quality management (TQM). The main problems detected while performing the study were: problems related to design such as delays, incompleteness, lack of details and inconsistencies, lack of planning and organization of transportation and delivery of materials, materials ordered on short notice or verbally, incomplete or inconsistent materials specification, lack of estimation of the amount of materials needed, delays in price surveys and in ordering materials, delays in checking stocks. The improvements were mostly related to supply planning, design phase management, qualification of suppliers and designers, and changes in the process flow. They concluded that although quality concepts and techniques seem easy to understand, their application in complex processes, such as materials supply management, tend to be rather difficult and time consuming.

dos Santos, Formoso, and Hinks (1996) devised a method of intervention in the flow of materials on building sites, based on the concepts of the new production philosophy. The principles of the method of intervention as described by them are:

- Short term benefits-quality and productivity improvement programs, scale improvements in the flow of materials can bring short term results, which can be easily noticed on site, and contribute for creating an improvement culture, leading to a major change in the company production philosophy
- Low cost improvements- development of the operations function role in construction companies is usually internally and externally neutral (reactive) to the needs of the company, may lead to the rejection of any kind of improvement that implies in high investment
- Without the need of significant technological changes-Without a corresponding improvement in operations management, radical changes in technology often leads a deterioration in the flow activities

They stated that it was verified after the research that the intervention contributed to changing the role of that professional, by providing a structured source of ideas. Images proved that the method proved to be the most powerful instrument of communication. Level of the flow of materials the researchers found positive effects both in terms of quantitative and qualitative parameters. The intervention can also be used as an audit process for a current strategy, assessing the existing practices in the diagnosis, analyzing those practices against benchmarks, and making confrontation with the perception of the managers.

Plemmons and Bell (1995) studied the key effectiveness measures of the industrial construction materials and which mechanism can be used for benchmarking. The objectives of the research were the following.

- Determine current effectiveness measures use in construction industry.
- Generate generic diagrams of flow of materials management
- Do a survey to determine which measures best communicate effectiveness
- Propose a mechanism for benchmarking the effectiveness of materials management systems

Abdul-Malak, et. al. (2000) investigated policies that could ensure that costs associated with materials purchasing are kept to a minimum. The research investigated the parameters used in characterizing construction materials, the contractor's purchasing policies and costs associated with purchasing of and holding materials, and the owner's payment policies for purchased materials. They identified three major cost categories associated with procurement and purchasing: purchase cost, holding costs and shortage costs. They identified payment policies from the contractor to supplier and from the owner to the contractor. After finishing the research they concluded that the owners should carefully check procurement policies by contractors. Owners should require a procurement schedule of all major materials against to partial payments apply. The contractor should be paid for materials purchased according to the schedule, so as to avoid paying for materials that are prematurely delivered to site. Control should be exercised over the contractor's ordering policies and payments to contractors should be scheduled properly to reduce overall costs of acquiring materials for construction.

Tuffour (1987) developed a materials management model to be used as a guide for contractor in developing countries, especially Ghana. The materials management was divided into three main parts. These parts are the materials management organization, purchasing procedures and relations with suppliers, and material utilization. The materials management organization presented a role and responsibility matrix that showed the responsibilities of several people from different departments.

Elzarka and Bell (1995) developed a prototype object oriented computer model for piping systems. They wanted to examine and determine potential expert systems applications to materials management. They stated that model is capable of executing automatic takeoff. Also, the program can generate purchase orders daily and allows for reduction in paperwork. The object oriented model was integrated with the design and the schedule. This integration allows updating the material takeoff automatically. In addition, changes in materials are updated automatically. They concluded that expert systems could improve the efficiency of material management systems.

The objective of the research effort by Jiang et. al. (2003) is to identify performance measure attributes for continuous process improvement in business process reengineering. They propose the multi-level decomposition process modeling with performance attributes (PMPA), which is a hierarchical structure. The PMPA was used to model an “as-is” organization and it is ideal to diagnose the non-value added activities. They present a case study of the measurement of performance for a residential builder.

3.5 Use of Technology for Materials Management

The tools used in the construction industry change constantly with the continuous changes of technology. Researchers are finding ways to apply those changes in technology to construction in order to improve production and lower the cost of the operations. This section presents how technology has been applied to construction by different researchers.

Bell (1986) studied the application of computer systems for materials management systems. He stated that computer systems were used to track and control engineered equipment and major fabricated items as well as small bulk materials items. In addition, he pointed out that a properly designed computer system tracks materials requisitions from the takeoff or requisition generation, through purchasing, expediting, and warehousing functions to final material issue and installation.

He classifies the materials management computer systems into two general categories: Database Systems and Comprehensive, integrated systems. A description of each system follows.

- Database systems- commonly used by owners, track status of engineered equipment and major critical materials items. The requisitions and purchases can be tracked and sorted according to data file parameters among other capabilities
- Comprehensive, integrated systems- commonly used by contractors, track status of bulk materials as well as engineered equipment. The requisitions and purchases can be tracked and sorted according to data file parameters. These systems are capable of interacting with the contractor’s estimating, scheduling and accounting systems. Other capabilities include: can interact with CAD drawings, computer takeoff assistance, analysis of vendor quotations, generation of purchase orders, trial allocation, generation of inventory reports among other capabilities

Bell stated that the computer system is only a single component of a properly designed and executed materials management system. In addition, he said that it is difficult to isolate the benefits that can derived by simply developing and implementing a computer system. However, the materials management systems do result in improved labor productivity, reduced bulk materials surplus, reduced materials management manpower on site, and improved vendor performance. The most significant of the benefits appears to be the improved craft labor productivity. Materials systems can be used by craft labor to plan their work according to material availability.

Stone, Pfeffer, and Furlani (2000) performed some research to develop a web based system for rapid tracking, identifying, and locating manufactured components on the construction jobsite. Their approach includes the use of bar codes, RFID, 3D long range coordinate measurement systems technologies, portable/wearable computers, wireless communications, high speed networking, temporal object databases, web-based data analysis, and 3D user interfaces. The research addressed the problem of identifying, locating, and tracking discrete construction components and sub-assemblies in a construction site. The primary objectives of the study were: to develop means for real-time tracking of sub-assemblies and components, to develop standards for component identification and tracking that the construction industry will adopt, to develop standard means to wirelessly transmit that information to a construction project database, to demonstrate the utility of these techniques on full scale construction sites. According to the researchers, the procedures and techniques were implemented in actual hardware and software and demonstrated live. The field data system is being integrated into a rugged hand held computer that will handle different coordinate measurement sensors including both laser and GPS.

Mascari Development Inc. developed a web based software tool which allows for materials management functionality. This tool defines the policies and procedures to order, process, receive and deliver materials. The main features of the software are: supply ordering, form ordering, money limit ordering, work orders among others.

Proctor and Gamble Co. developed a web based construction purchasing system. The main objectives of this system are: work process simplification, achieve cost savings and to make purchasing more responsive/timely, allow real time access to purchase data, standardize purchasing systems among others. They stated that the system produce a more efficient time from requisition to delivery, rework is avoided because electronic data minimizes paper shuffling, accuracy of data is improved, and the ability to place emergency order among others.

ProcureIT™ is an enterprise-wide electronic procurement and MRO solution that automates the entire purchasing and materials management process that was developed by Verian technologies. This web-based Intranet application is deployed directly to individual user desktops and gives you complete control over all of your purchasing activity. The program has an easy-to-use interface and is designed for organizations that want to lower resource costs, decrease cycle time, increase end-user satisfaction, and improve control in their procurement and materials management processes.

QMS Materials Management System was developed by QA Software. The purpose of QMS in regard to materials management include: management of changes to the bill of materials, automatic generation of inquiries and purchase orders for materials, management of the impact of a changing bill of materials on material orders, management of expediting of materials, control of material deliveries, management of material shortages both on fabrication and construction, control of material issues and movements, inventory/stock control management, management of material traceability, progress monitoring. The program offers a variety of modules to keep track of changes to the bill of materials, summarize bill of materials in minutes, with automatic documentation generation for both bid packages and/or purchase orders, keep a complete history of all changes to purchase orders, recording the receipt of materials simple with typing only of the quantities received, analyze what can be fabricated or installed, automatic generation of issue slips/dockets and/or movement dockets to save time and improves accuracy. At all times the exact quantities of material at any location is known.

3.5.1 Bar Codes Applications to Material Management

Bar code applications in construction are mostly intended to provide accuracy in data collection, to improve productivity and to save time in the data collection process. Typically, bar codes are used for materials and inventory management. The scope of bar codes extends beyond materials management. Bar codes provide the advantage of relatively error free data collection, which improves productivity and avoid errors. Some construction firms that use bar codes claim that it saves time, money and labor while improving the accuracy of inventory.

The Construction Industry Institute funded a research project in 1987 to study potential applications of the bar code technology in the construction industry. Bell and McCullouch (1988) and Stukhart and Pearce (1988) presented the results of these studies. Bernhold (1990) provided a background on the technical details, suitability of bar codes for construction and field testing of bar codes in the construction site environment. Blakey (1990) demonstrated the use of bar codes in parts inventory and scheduling maintenance for military facilities. Stukhart and Cook (1990) discussed the approaches used by other industries to develop bar code standards and how these approaches could be used to develop a bar code standard for the construction industry. Rasdorf and Herbert (1990) presented the applicability of bar codes for the development of a construction information management system for the control of information. McCullough and Lueprasert (1994) studied the applicability of 2D bar codes for the construction industry.

The major applications of bar code to material management identified in previous research can be identified as follow:

- Field material control

  Bar codes have different applications for field control of bulk and engineered materials. This technology can be used to control receiving, inspection, storage and issue of consumables, parts, equipment, and all the items that could be controlled with bar codes. A report can be kept when materials are taken from the storage. These materials can be scanned and the report of issuance of materials can be completed.
- Warehouse maintenance and control

  When materials are received and stored, the assigned location can be entered into the computer system by scanning the bar code of the particular material. Bar codes allow performing inventory by scanning the bar codes of the materials. As the project progresses and materials are used, a better overall picture of available materials is accessible for forecasting and scheduling purposes.
- Inventory control applications and tool and consumable material issue

  Consumable materials, such as rain coats, gloves, safety glasses, are subject to abuse and misuse. Although some time might be spent entering bar code data into the computer system, it might eliminate misuse of consumables. The inventory can be kept up to date as the materials and resources are consumed.
- Purchasing and accounting

  Forms used for purchasing or other functions related to cost control can be printed with bar codes. Shipping forms from vendors can include bar codes to facilitate the receiving process.

3.5.2 Radio Frequency Identification (RFID) Applications to Material Management

Similar to bar code, RFID applications in construction are mostly intended to provide accuracy in data collection, to improve productivity and to save time in the data collection process. A Radio Frequency Identification (RFID) system is an automated data collection system similar to bar code. The tag used in RFID can be compared to the bar code and the wand used to scan bar codes can be compared to the receiver used in RFID. The principal difference between bar code systems and RFID is that in RFID the data collection process is done autonomous. No line of sight is needed for data collection. In the case of the bar code system, the bar code has to be scanned with a wand. In addition, in RFID systems data is carried in the tags. RFID can be viewed as a wireless link used to identify objects individually. This technology is primarily used in places where the bar codes can't be used. Some of the applications in which RFID tags could be used and in which bar code could be inappropriate include situations in which there is no sunlight or place in which the tags get covered with grease or dirt.

Many researchers have used RFID in previous studies to apply them to construction. RFID systems could be used in the same way in which bar codes are used. However, the cost is a major factor. There are other applications in which RFID systems work better than bar code systems. RFID had been used for material tracking and material receipt in the construction industry.

- RFID allow tracking materials as the move in the jobsite since direct contact is not required for data collection. This can avoid theft and lost since managers can notice when materials are not where they are supposed to be.
- Materials Receipt
  Materials can be easily verified as they arrive to the site. The type of materials received can be known easily and verify if the right quantities were received.

3.5.3 Handheld Devices for Material Management

Recent advances in technology have proven to be very useful to the construction industry. Portable computers, wireless data transmission, among others, have been used for asset tracking, data collection and transmission. This data collection and transmission has been used to monitor performance with the ultimate goal of improving productivity and lower costs. Personal digital assistants (PDAs) have been used in the construction industry for different purposes. These devices have been used to develop applications in scheduling (Updater), tools tracking and control (ToolTrac), and tracking of personnel (TimeTrac). Presently, different types of software are available that easily allow building customize applications to be used in portable devices. The available software allows building and editing applications in Pocket PCs. The availability of these resources makes possible the development of applications for material management and inventory control. In addition, bar code readers could be used in conjunction with Pocket PCs for automating the inventory process. Technology changes constantly, therefore the Pocket PC hardware and software are constantly evolving with these changes in technology. There are continuous efforts to develop new systems and/or improve the current devices. Some of these improvements include the ability to install more powerful processors, to use storage devices of small size in conjunction with the Pocket PC. These improvements allow these devices to be used as stand alone systems. The compact size and light weight of the Pocket PCs make them suitable to be easily carried around and used at the construction site to perform various tasks

3.6 Other Research Related to Materials Management

Other research efforts addressed other issues in the materials management process. Proverbs, et. al. (1995) examined the materials management procedures and wastage levels. Plemmons and Bell (1995) identified key effectiveness measures of the industrial construction materials and which mechanism can be used for benchmarking the effectiveness of materials management systems. Elzarka and Bell (1995) examined the potential of expert systems applications for materials management. O'Brien (1998) performed empirical studies with supplier and subcontractors to demonstrate inability of existing construction techniques for planning and costing used to account for changes in cost. Abdul-Malak, et. al. (2000) investigated various parameters used in characterizing construction materials including the contractor's purchasing policies and costs associated with procuring materials, and the owner's payment policies for purchased materials policies to ensure that costs associated with materials purchasing are kept to a minimum.

3.7 Materials Management for the Electrical Contracting Industry

Rowings and Federle (1995) conducted research on systems for tool and material control. The objective of the research was to investigate which tool and material control systems would be more suitable to the needs of the average electrical contractor. Glanivich (2002a) investigated the services that distributors (i.e. suppliers) can provide to electrical contractors. Glavinich (2002b) investigated the benefits of using vendor managed inventory (VMI) and how inventory cost and the risk of stockouts can be reduced by using this approach. All these research efforts were funded by the Electrical Contracting Foundation Inc. Thabet and Perdomo (2003) investigated current material management practices in the Electrical Contracting industry. The investigation considered the entire range of activities necessary for procuring the needed material, starting with the estimating process and ending with site delivery, distribution and storage logistics. Research outcomes included documenting the problem bottlenecks in the supply chain as well as identifying and classifying the various criteria that influence the decision process for procuring material. A conceptual framework for the material supply chain process was developed based on various discussions and interviews with several NECA members. The framework considered many decision alternatives including material type, supplier availability and relationship, procurement options and incentives, quantities needed, delivery dates, storage alternatives, and project schedules.

3.8 Cultural Change in Construction

Cultural behavior and its resistance to change have been extensively investigated and documented in all industries from manufacturing, corporate business to construction. The construction industry is very resistant to change. The *"if it is not broken, don't fix it"* attitude is typical in construction. Implementation of new innovative methods might be difficult in such environment, therefore a study of the culture encountered in construction is essential for this study. Gorman (1989) states that every company has its own culture, therefore there is no ideal culture to guarantee success and every company has to be investigated separately. Riley and Clarke-Brown (2001) investigated and compare the culture found in a construction company with the culture found in manufacturing companies. They wanted to investigate how suitable it would be to incorporate manufacturing techniques into the construction industry due to the resisting culture found in the construction industry. Davis and Songer (2003) investigated the resistance to adopt technological changes in the A/E/C industries. Koivu et al. (2003) investigated how the different cultures within a company affect project performance and the adoption of technology. Beliveau (2003) investigated the cultural issues of implementation an advanced web based information technology system for construction.

3.9 Supply Chain Management for the Manufacturing Industry

Similar to construction, for manufacturing material management is a critical activity. The smooth flow of operations depends highly on the availability, control and handling of materials. In addition, in order to minimize overall costs of the final products, minimization of the costs related to material handling, ordering and storage is essential. This is the reason why improvement of the supply chain management for manufacturing has been a target of numerous research efforts.

Among the published efforts in supply chain and material management for manufacturing are the works performed by Ballot (1971), Dag (1974), Tersine and Campbell (1977), Beekman-Love (1978), Ammer (1980), Bailey and Farmer (1982), Gossom (1983), Cavinato (1984), Arnold (1991), and Dobler and Burt (1996), Simchi-Levi et al. (2000), and Leenders et al. (2002). Some of the work of these researchers was used in the introduction to material management in Chapter 2.

Dong (2001) developed a modular modeling and analyzing approach, based on object-oriented Petri nets, to facilitate the modeling and verification analysis of supply chain workflows. In addition, he developed a network of inventory-queue models for the performance analysis and optimization of an integrated supply network with inventory control at all sites. He also developed simulation models for understanding decision-making issues of the supply chain network configuration in an integrated environment.

3.10 Knowledge Management

The task of managing knowledge comprises many disciplines. Davenport (in Liebowitz, 1999) states that knowledge management has been linked to organizational performance and strategy in areas such as evolutionary economics, the economics of innovation, and technology management. He points out that knowledge management is characterized by terminology, approaches, methods and organization that are separated from the organization that is served by the km concept. Moreover, he states that the km concept is a theoretical concept that has not been tied to strategy and performance in practice and had yet to enter the business world.

Beckman (in Liebowitz, 1999) states that the field of knowledge management is just a little over 10 years old. He states that Karl Wiig is one of the pioneers of the field and could probably be its founder. He points out that several authors have been concerned with creating a framework and methodology for knowledge management. He states that the interest for knowledge management discipline boomed after 1996.

Barclay and Murray (1997) state that a number of management theorists have contributed to the evolution of knowledge management. Among these they mention Peter Drucker, Paul Strassmann, and Peter Senge. They point out that work done in the late 1970s at Stanford by Everett Rogers and the work at MIT by Thomas Allen in information and technology transfer, have contributed on how knowledge is produces, used and distributed among organizations. They argue that in the 1980s the development of systems for managing knowledge emerged and term knowledge management emerged. In 1989, knowledge management related articles started to appear in journals and the first books on the subject were published. In the mid 1990s, the internet was used as a tool for knowledge management and share initiatives. Conferences and seminars on the subject started to appear. In 1994 the results of a knowledge management survey conducted among European firms were published, and the European Community began offering funding for KM-related projects through the ESPRIT program in 1995.

Gamble and Blackwell (2001) suggest that the ideas behind knowledge management go back as far as the 1950s with the use of quantitative management techniques and structured management approaches. They state that the approach to knowledge management has evolved from corporate organization in the 1960s to creating enterprise integration through knowledge sharing culture in the 2000s. Messner (2003) presents the development of a detailed information architecture for structuring the knowledge and information for the A/E/C industry.

All the above-mentioned research certainly contributed to the research effort presented in this document. Most of the research work investigated the activities that comprise the materials management independently with no integration of the process. The integration of the departments that deal with materials related activities is essential. By using and building upon some beneficial features from some of these research works, it is expected that this research will be able to improve the materials management system for the electrical contracting industry. The next chapter will present an overview of the electrical contracting industry and the current material management practices in this industry.

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CHAPTER FOUR: AN OVERVIEW OF THE ELECTRICAL CONTRACTING INDUSTRY AND CURRENT MATERIAL MANAGEMENT PRACTICES

Similar to other industries, a successful business in construction is a team effort. The different members of the team have to coordinate design, estimating, material purchasing and installation in order to maximize productivity, earn a profit at the end of the project, and complete the project within time and budget. It is difficult to achieve efficient installation of the components and the maximum production of the crew at every instant. The contractor has to plan and schedule the purchasing, expediting, receiving, storage, and installation of the materials by coordinating the different parties involved (i.e. estimating, job managers, and field personnel). In addition, in order for the company to be successful, the company should consist of individuals trained to perform the tasks assigned to them in an effective way (Johnson, 1986).

4.1 Electrical Contractors Industry- Background

Electrical contractors are in the business of providing services that will allow customers to use electricity. In this era, almost everyone uses electricity; therefore anyone can be a customer for an electrical contractor. The environment of the electrical contractors industry presents a situation different from other business. In the 1970s, most of the electrical contractors were ready to provide any service requested by the customer (Johnson, 1986). Nowadays, some of electrical contractors are special trade and they could do work in a wide range of areas with the electrical business. Many contractors specialize in an area of work in the electrical industry and can perform work only in the area of their specialization.

The electrical contracting market has expanded in recent years compared the other areas of construction. Employees in the electrical contracting industry account for around 13%

of the total employees in the construction industry (Electrical Contractor, 2001). The nature of the electrical contracting business requires that a large volume of sales needs to be achieved in order to support the company. Many electrical contracting companies are not necessarily large companies, therefore the company has to provide services efficiently and at the lowest cost possible in order for the company to remain in the business. Contractors should keep a good reputation, trust, and they should serve all customers efficiently (Johnson, 1986). In the last 14 years the electrical contracting industry has tripled their volume of sales (Electrical Contractor, 2001). Figure 4.1 shows estimated sales and material purchase by electrical contractors between 1992 and 2001. In addition, the number of employees in electrical contracting activities increased by more than 350,000. This includes production and overhead employees. Production employees are those that perform actual hands on job in the field. Overhead employees are office and managerial employees. The sales per employee also rose significantly during the same period. This increase in sales brought an increase in profit per employee (Electrical Contractor, 2001).

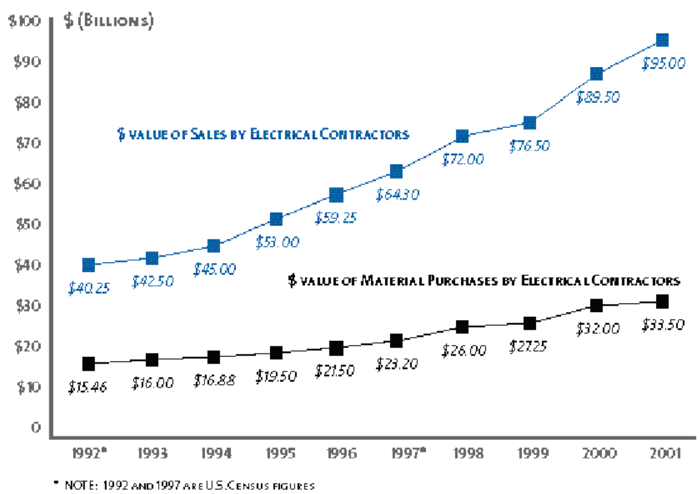

Figure 4.1: Estimated Sales and Material Purchase by Electrical Contractors (Source: Electrical Contractor)

The expansion of the electrical contracting industry has not been only in the amount of dollars that they receive for their job and employees involved, but in addition in the types and diversity of jobs. Typically the electrical contractors had worked as a subcontractor for the prime contractors. This tendency is changing and in the 1990s electrical contractors got engaged in a variety of previously uncommon working arrangements.

Some of these arrangements include the electrical contractor serving as prime contractor to the owner, and also the use of “negotiated” approaches between the owner and the electrical contractor (Electrical Contractor, 2001). Figure 4.2 presents some of the roles that the electrical contractors can assume. Some of the projects in which this tendency can be seen include hotels and data centers in which telecom and other technology features need to be installed. It is fair to say that the electrical contracting market is in transition from the traditional subcontracted power jobs to the technology prime contracts (Electrical Contractor, 2001).

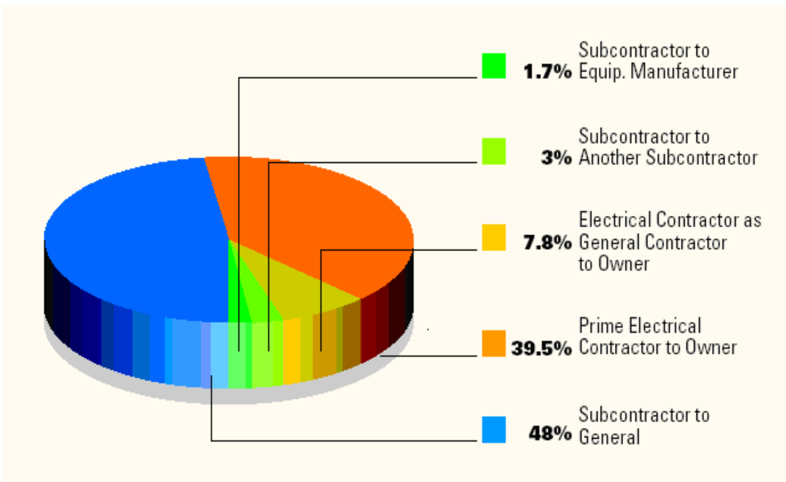

Figure 4.2: Roles that the electrical contractors can assume (Source: NECA)

Traditionally electrical contractors have been involved in residential, commercial, industrial, institutional and other types of work. Most of the contractors that are involved in commercial and industrial projects do not work in residential projects. In today’s business environment, electrical contractors can be involved in projects involving power, as well as other projects that don’t involve power at all. Some of them are now engaged in new construction and in other areas such as modernization, maintenance, repair and preparing existing facilities with the latest video/data/voice systems. There is an increase in demand for modernization and maintenance of buildings. Owners of commercial and other type of buildings seek to provide state of the art facilities. In addition, many companies want to offer Internet facilities for their customers, while others are establishing data companies. Modernization has become an area of continuous work for electrical contactors. Furthermore, they are involved in work not necessarily described as traditional construction such as fiber optics installation and close circuit systems. Some of the traditional power contractors had evolved using their management skills and workforce to perform other installations such as fiber optic. This does not mean that the electrical contractors do not work as subcontractors for power purposes, but the role is changing to include more specialized technology prime contracts (Electrical Contractor, 2001).

4.2 Services Provided by Electrical Contractors

Because of these changes and the new type of contracts in which these contractors are involved, the type of services that they can provide has also changed. Some of the services that they can provide are design, selection and purchase of equipment, installation of electrical and non-electrical components, pulling of wire and cable, and testing of facilities. Electrical contractors don't provide design in every job, but the number of jobs in which they are providing this service has increased. This is mainly because of the present trend in changing from the traditional design/bid/build to design/build. In a design/build the electrical contractor is involved in the design. This involvement eliminates incomplete drawings. In modernization projects, the electrical contractor designs much of the systems to be implemented. The relationships between the parties involved in a design/build project are closer than in a traditional project, which requires more involvement of the electrical contractor and this involvement could represent an increase in profit. In traditional projects they receive a set of drawings and specifications, usually unclear and incomplete, that they have to follow. In design/build projects they are more involved and can get more detailed drawings and specifications and this could result in a better final product. In addition, this involvement brings with it more involvement in the product selection process. Their role in determining which products will be used in the project has increased. Most of the time the electrical contractors are picking the type of materials to be used in a project. In many cases the owner buys equipment directly, but it is the electrical contractor who advises and approves the equipment to be ordered. In some cases the plans are not complete and some discretion is left to the electrical contractor. Contractors are considered product experts, therefore owners ask for their advice more frequently. Moreover, in some cases the electrical contractor submits alternates and frequently the owner asks for value engineering to lower costs (Electrical Contractor, 2001).

4.3 Materials Purchasing by Electrical Contractors

Given the change in the roles that the electrical contractors play, including nontraditional roles, the change in the area of materials purchases is evident. The Electrical Contractor Magazine conducted a study called Profile 2000, where the contractors were asked about their top three concerns when buying material. For the majority, price was the number one concern. However, the study concluded that cost was named first by less than 50% of the respondents, no matter what size business. This figure would have been higher in the 1980s. As times have changed, apparently, more and more contractors are changing with them. Table 4.1 shows a comparison on materials purchasing criteria between 1997 and 1999. As can be seen from this table, the price criteria was the top priority in 1997, but availability was the top priority in 1999 (Electrical Contractor, 2001).

1999	**1997**
1 Availability	**1** Cost/Price
2 Quality/Reliability/Durability	**2**
3 Cost	**3** Availability
4 Service	**4** Ease of
5 Ease of	**5** Service
6 Brand Name	**6** Brand
7 Specified Brand-	**7** Delivery

Decreasing Priority

Table 4.1: Materials Purchasing Criteria Priorities between 1997 and 1999 (Source: Electrical Contractor)

Electrical contractors rely and buy the majority of their materials from their local suppliers. However, for works involving voice/video/data technology they have to buy materials from other places, because their local distributors are not ready to supply the materials that they need in this category. This situation has forced to find other suppliers including catalog suppliers and other distributors. The relationship with suppliers can be critical and could decide between a profit and loss. Suppliers offer product capacity information, availability, and delivery. With this information the contractor can finance his operations and plan the work depending on the time of arrival of materials. Because of the impact that a supplier can have in the financial and production aspects of contractors, electrical contractors prefer to do business with more than one supplier. By having more than one supplier they can avoid product mispricing (i.e. a supplier charging more for products and materials), and they could have a bigger selection of products. Most contractors are not buying products using e-commerce. The primary reason is that they don't have the facilities to store all the materials needed for a project and then deliver them to site as needed. This will require a materials handling system and the majority of electrical contractors are looking to carry less inventory by relying on their local distributors to deliver materials when they are needed (Electrical Contractor, 2001).

4.4 Typical Products Used By Electrical Contractors

In order to achieve the maximum productivity of the crew it is very important to have the material, equipment and tools at the right place and when needed. Common literature classifies the products used by electrical contractors into two major categories: power products and equipment, and low voltage products and equipment (Electrical Contractor, 2001). Power products and equipment are products used to deliver energy to the customers and products that use that energy. Among such products and equipment the following examples can be included:

- Boxes & Fittings
- Emergency Lighting
- Fixtures (lighting)
- Floor Boxes
- Fuses
- Lamps (lighting)
- Lighting Controls
- Metal-clad Cable
- Meters & Sub meters

Low voltage products and equipment refer to products that are not directly related to energy transmission. Examples of such products and equipment include:

- Category 5 LAN Copper Cable
- Fiber Optic Cable
- Fiber Optic Components
- Fire Alarm Systems
- Intercom & Nurse Call Systems
- Premise Wiring Hubs (voice/data)
- Raceway (voice/data)
- Routers (voice/data)
- Security Equipment
- Smoke Alarms

Johnson (1986) states that there is a category known as the expendable or consumable materials. Expendable materials are materials that are used while installing the material and equipment on electrical jobs. These materials are needed in the installation, but they do not remain as an integral part of the installation work. Field personnel buy these materials day by day as needed and as they are consumed. The following materials are examples of expendable materials:

- Batteries
- Broom
- Brushes
- Chisels
- Cups
- Drills
- Bolts
- Gasoline
- Oil
- Chalk lines
- Thinner
- Lumber
- Tape
- Soap

- Plaster

Based on field interviews to electrical contractors, in general, materials purchased by electrical contractors fall into two categories; miscellaneous material or commodities, and major materials. Miscellaneous materials refer to off-the-shelf items such as cables, conduits, straps and fittings. Major materials include switch gears, lighting fixtures, alarm systems and other items that need to be designed/fabricated specifically for a given job. Some definitions for major and miscellaneous material (http://contractorreferral.com) follow.

- Transformer- A device that changes, or transforms, alternating current from one voltage to another.
- Switch- A device that closes and opens an electric circuit by moving two electrical conductors into contact to close the circuit or separate them to close the circuit.
- Contactor- A device similar to a switch that uses contact blocks forced together to close the circuit or separated to open the circuit.
- Switchgear- A freestanding assembly including primary (disconnect) switches, secondary (feeder) switches, and overcurrent protection device (fuses and circuit breakers).
- Lighting Fixture- An assembly having one or more lampholders, or a lampholder used in lieu of such an assembly.
- Control Panel- A panel, cabinet, or enclosure containing two or more controllers, contractors, relays, or other control devices for the control of electrical circuits, equipment, apparatus or system.
- Circuit Breaker- A switch which stops the flow of current by opening the circuit automatically when more electricity flows through the circuit than the circuit is capable of carrying; resetting may be either automatic or manual.
- Distribution Panel- The main electrical control center, which contains switches or circuit breakers, is connected to the service wires, and delivers current to the various branch circuits.

- Substation- an assembly comprised by voltage switches and circuit breakers, a step down transformer, meters, buswork, and secondary low voltage switchgear
- Raceway. Any channel courses supporting and protecting electrical conductors, including conduits, wireways, surface metal raceway, cable trays, floor and ceiling raceways, busways, and cable bus.
- Panelboard- A single panelboard or group of panel units designed for assembly in the form of a single panel including buses and with or without switches or automatic overcurrent protective devices, or both, for the control of light, heat, or power in a cabinet or enclosure placed in or against a wall or partition and accessible only from the front; also called a Switchboard.
- Conduit- A protective sleeve or pipe commonly used for individual electrical conductors
- Busway- An assembly of copper or aluminum bars in a metallic housing used when it is necessary to tap onto an electrical power conductor.
- Electrical Metallic Tubing (EMT) - Unthreaded light weight piping for running electrical conductors; easier to handle than rigid conduit and installed more rapidly because of the type of non-threaded fittings used with it; also called Thin Wall Conduit.
- Flexible Conduit- Electrical conduit made of a spirally wound metallic strip.
- Aluminum Conduit- A pipe constructed of a light alloy material used to enclose electric wires to protect them from damage.
- Plastic Coated Conduit- A type of conduit for electrical wiring that is used around moist areas and highly corrosive fumes.
- PVC Conduit- Lengths of rigid plastic pipe made of polyvinyl chloride.
- Steel Conduit- A pipe, tube, or channel used to enclose electric wires or direct the flow of a fluid.
- Fitting- A device used for connecting pipes together.
- Cable Fitting- Couplings, elbows, tees or unions used to form a junction or connect cable lines together.
- Hanger- A device attached to walls or other structure for support of pipe lines.

- Outlet Box- A box or container which houses an electrical outlet and its connections.
- Cable- A bundle of two or more electrical conductors.
- Wire- A metal drawn out into the form of a thread or thin flexible rod, used for fencing, binding, or to conduct an electrical current
- Bolt- A threaded metal rod or pin for joining parts, having a head and usually used with a threaded nut.
- Nut- A small square or hexagonal flat piece of metal or other material with a threaded hole through it for screwing on the end of a bolt to secure it.

4.5: Current Materials Management Practices in the Electrical Contracting Industry

A previous research work by Thabet and Perdomo (2003) has investigated current materials management practices in the EC industry. The investigation considered the entire range of activities necessary for procuring the needed material, starting with the estimating process and ending with site delivery, distribution and storage logistics. Research outcomes included documenting the problem bottlenecks in the supply chain as well as identifying and classifying the various criteria that influence the decision process for procuring material. A conceptual framework for the material supply chain process was developed based on various discussions and interviews with office and site personnel from the electrical contracting industry in Northern Virginia (NOVA), Southwest Virginia, Tennessee, Maryland and North Carolina. From the information acquired from these interviews, five distinct phases that comprise the process were identified: 1-Bidding Phase, 2-Sourcing Phase, 3-Materials Procurement, 4-Construction Phase, 5-Post-Construction Phase. The following subsections will discuss the five phases in more detail.

4.5.1 Phase 1: Bidding

The materials management process starts from the time that the contractor receives the drawings and specifications. The materials takeoff and identification process is the first step in this phase and involves identifying the materials needed as well as any special requirements or special materials to be used in the project. Quantities needed are estimated and a bid package is put together and submitted, typically to the GC. Figure 4.3 presents a diagram of the bidding phase.

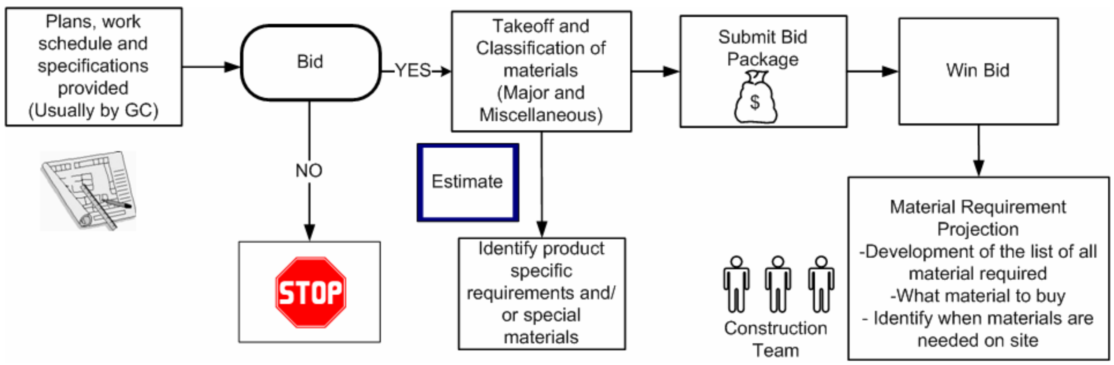

Figure 4.3: Bidding Phase

In general, materials used by electrical contractors can be classified into two categories: miscellaneous materials or commodities, and major materials. Miscellaneous materials refer to off-the-shelf items such as cables, conduits, straps and fittings. Major materials include switch gears, lighting fixtures, alarm systems and other items that need to be designed/fabricated specifically for a given job.

Most of the contractors create "electronic" or computerized estimates by using a software package (e.g., Accubid, TRF, and ConEst) or by preparing a customized program that is suitable for their needs by using a computer application such as Microsoft Excel®. The majority of the companies that make computerized estimates use assemblies (e.g. gear box) for material takeoff that are embedded in the software packages rather than estimating the individual components (e.g. wiring or piping). The use of these assemblies makes the estimating process easier and faster. Other companies prepare manual estimates, which are verified several times prior to submitting the bid. Some companies use internal cost codes for material takeoff and identification that are assigned to the material being estimated.

In some companies, project managers are involved in the estimating phase. The involvement of the project managers could lead to the preparation of more realistic estimates due to the project manager's knowledge of electrical systems, materials and equipment. In other companies, the estimate is prepared by the estimating department and no field personnel are involved. However in these companies, the estimate is verified by the EC once the contractor successfully wins the bid.

Typically, databases of historical prices are used to prepare the estimate and subsequent bid packages. For major material, contractors rely on prices from suppliers and/or manufacturers or they use prices from a database of historical prices. These databases of prices are updated periodically to reflect current market prices. If there is a blanket or yearly contract for a particular item, the prices for commodities under the yearly contract are known. This blanket contract ensures that the price for those commodities will be fixed for a predetermined period, usually one year. In some instances, trade catalogs are used for the bid prices when there are no blanket orders or a database of prices is not available. The purchasing department verifies the prices used in the estimate prior to submitting the bid.

After successfully winning the bid for a particular project, some companies schedule a kick-off meeting that includes the superintendent, the project manager and all the foremen. At this meeting, the foremen and the project manager re-estimate the quantities for major material and commodities. They generate a material requisition schedule (e.g. release forms) specifying material types, quantities needed, dates when the material should be delivered and any additional information needed for clarification. In addition, any notes related to particular items and the drawings for the job are included. Other companies do not re-estimate the project as long as the quality and clarity of drawings provided is good and no changes were made to the design. In these companies, the initial estimate is verified 2-3 times before submitting the bid.

4.5.2 Phase 2: Sourcing

The first stage in this phase is the selection of reputable suppliers and manufacturers. The selection of suppliers is critical and the contractor needs to verify that the supplier is capable of delivering the right material (i.e. type, quality and quantity) when needed (i.e.

at dates specified). In general, most materials (miscellaneous and major) are purchased through suppliers/distributors. Most EC's prefer to buy materials from their local suppliers and from suppliers with whom they had worked before. Some companies have specialized agents within their purchasing department for supplier selection and procurement. In order to do business with these suppliers, they need to verify that the supplier is capable of delivering the material when needed. In addition, in order to get reasonably good prices for the material, they request quotations from different suppliers. Suppliers are usually selected based on lowest price, however, contractors may consider suppliers with higher prices but that will provide better service or that have a record to supply the right material in the quantities needed at the times specified. In some situations incomplete proposals from suppliers may delay the selection process.

The purchasing process is different depending on the type of material ordered. For miscellaneous materials (commodities) most contractors select their suppliers/distributors based on a bidding process, unless there are blanket purchase orders or yearly contracts for certain types of commodities. Under the bidding process, the contractor requests quotations for that material from suppliers that the contractor trusts and from suppliers that the contractor has worked with on previous projects. In the case of a blanket contract, the contractor buys the commodity items under the contract from that particular supplier. Due to high competition in their market areas, some contractors don't use blanket or yearly contracts because they are able to get better prices at any time by requesting bids from their suppliers. Typically, the contractor requests prices for an amount of material that is less than the amount that was estimated (e.g. 80% of original estimated material needed). This approach is used to avoid material surplus on the job-site. Based on the quotations submitted, the contractor selects the supplier.

For major materials, the contractor most often negotiates prices directly with the manufacturer, if the manufacturer is specified in the contract documents. However, the contractor has to buy the material through the supplier/distributor after a mark up has been applied. Otherwise, the contractor requests bids from different qualified manufacturers that produce the required material type. Getting the manufacturers to bid against each other is beneficial for the contactor because he can get better prices. The contract is awarded to a manufacturer after this negotiated or bidding process is complete. As opposed to miscellaneous material, the contractor typically purchases the total amount that was originally estimated for major materials. This is because major materials need to be fabricated and require longer lead times. If the amount requested is less than the amount originally estimated and there are shortages, the contractor will have to wait until more material is fabricated, which can cause disruptions and delays.

Typically, after the contract has been awarded to the supplier, an agreement is set by the issuance of a temporary purchase order. This temporary purchase order is an assurance to the supplier that the contractor will buy the material from that particular supplier. After the contract is awarded, the supplier issues submittals, usually 10-12 copies, for major material and certain miscellaneous material to the electrical contractor. The EC submits them to the GC who in turn submits them to the engineer/owner's representative for approval. The temporary purchase order is approved and becomes a purchase order once the submittals have been approved by the engineer/owner's representative. This process is illustrated in Figure 4.4.

4.5.3 Phase 3: Material Procurement

The material requisition and expediting phase is very critical to the success of a material management process. The person in charge of procuring materials or the purchasing department, in the case of a large company, needs to ensure that the correct materials in the correct quantities are delivered. This person also needs to verify the release dates at which the material is needed and to clearly specify those delivery dates and the location of delivery to the supplier.

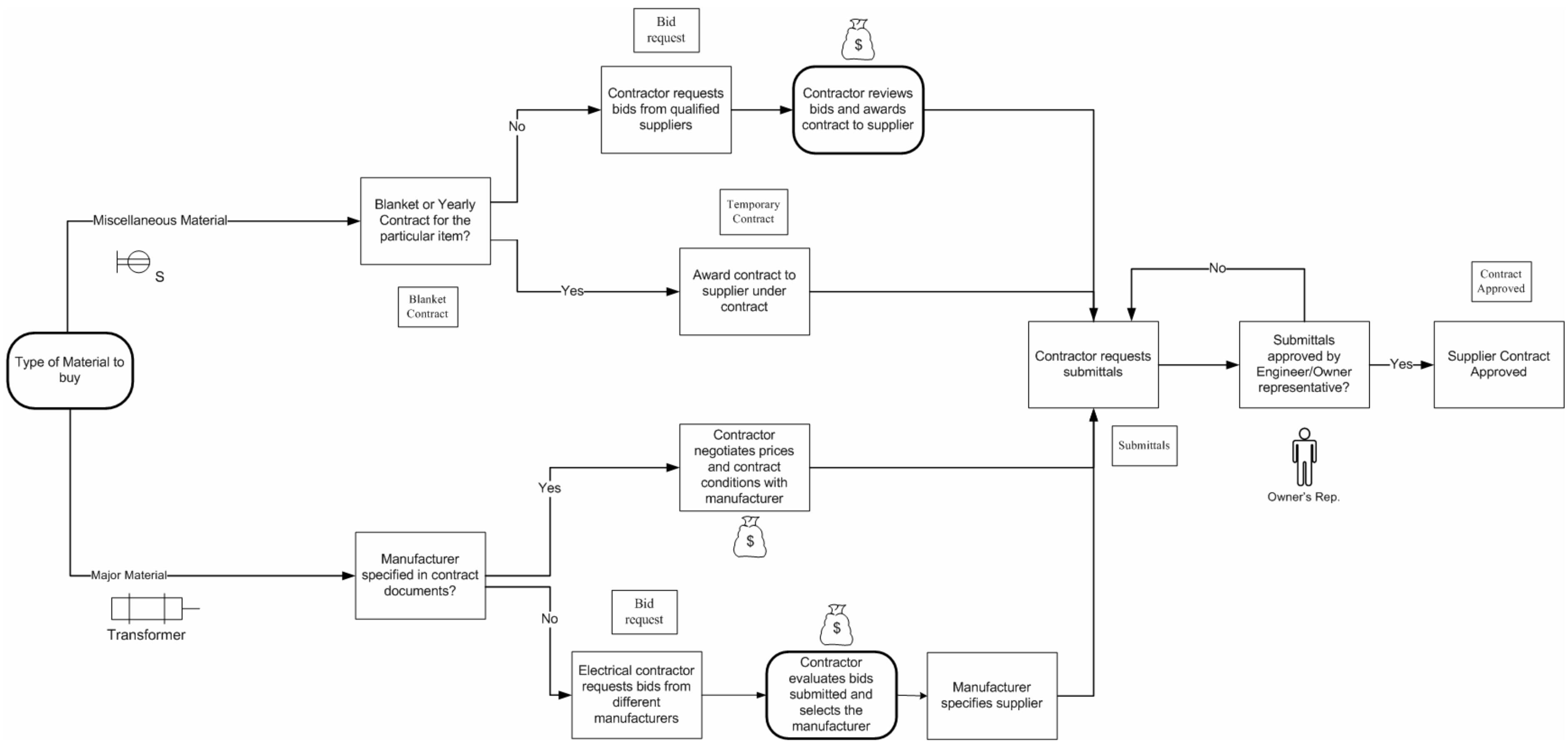

Figure 4.4: Sourcing Phase

Once a supplier is selected and the material is ordered, the contractor has to follow up systematically the status of ordered material to insure delivery to the jobsite in the quantities needed and within the timeframe specified. In many companies, this process starts with the generation of a material requisition schedule. In large jobs, the schedule is usually prepared by the site staff and then is sent to the purchasing department for material request from the suppliers/distributors under contract. In smaller companies or in smaller size jobs, material may be requisitioned directly by the field personnel. In companies that have a warehouse, the purchasing department first verifies availability of materials in the warehouse before requisitioning any materials from suppliers. Figure 4.5 presents the material procurement (requisition and expediting) phase.

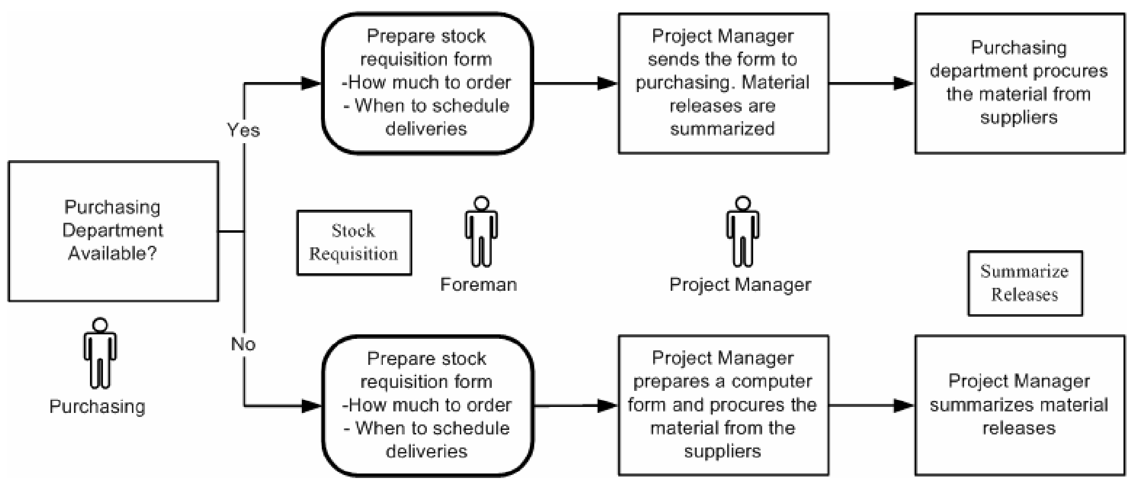

Figure 4.5: Material Procurement Phase

Once a material requisition schedule is in place, individual requisitions are generated from the construction site by either the foreman or the project manager. A material requisition starts with the generation of a material release form. In this form, the type of material needed and the quantities and the dates when the material is needed are specified. In the case that the foreman prepares the material release form, it is sent to the project manager. The project manager is in charge of requesting the material from the purchasing department. The purchasing department requests the material from the supplier specifying the material type, quantity needed, time when the material is to be delivered and instructions on where to deliver.

Small companies may not have a purchasing department and the project manager is in charge of procuring the material directly from the supplier. Similar to the case in which there is a purchasing department, the material requisition process starts from the construction site by either the foreman or the project manager. Once a release form is generated, suppliers are contacted for procuring the material needed. The type of material needed, quantities and the time when the material is needed is specified to the supplier.

4.5.4 Phase 4: Construction

Material delivery usually occurs during the construction phase. Material is generally requested for delivery to the jobsite. In some instances material delivery to the jobsite may not be feasible due to storage or access limitations. In this case, the material is delivered to other locations such as the contractor's warehouse, a pre-fabrication shop or another subcontractor storage area. Figure 4.6 depicts the different material delivery and storage options.

Material is delivered to a warehouse in cases such as when critical specialty items are ordered early and are not going to be installed immediately, when storage area at the job-site is unavailable, or if the material will be used for pre-fabrication. Storage of the material at the warehouse prior to moving it to the jobsite increases indirect costs due to re-handling. Here too, we can see the role of decision analysis and information systems in helping the contractor tradeoff these costs against the costs of shortages and more shipments.

Some companies utilize a pre-fabrication shop facility to assemble components in a controlled environment. Advantages of pre-assembly include increased production time and reduced labor costs compared to performing the assembly process in the field where poor weather conditions and space limitations may cause work delays. The increase in productivity and savings in labor costs out weigh additional costs encountered due to pre-fabrication and re-handling.

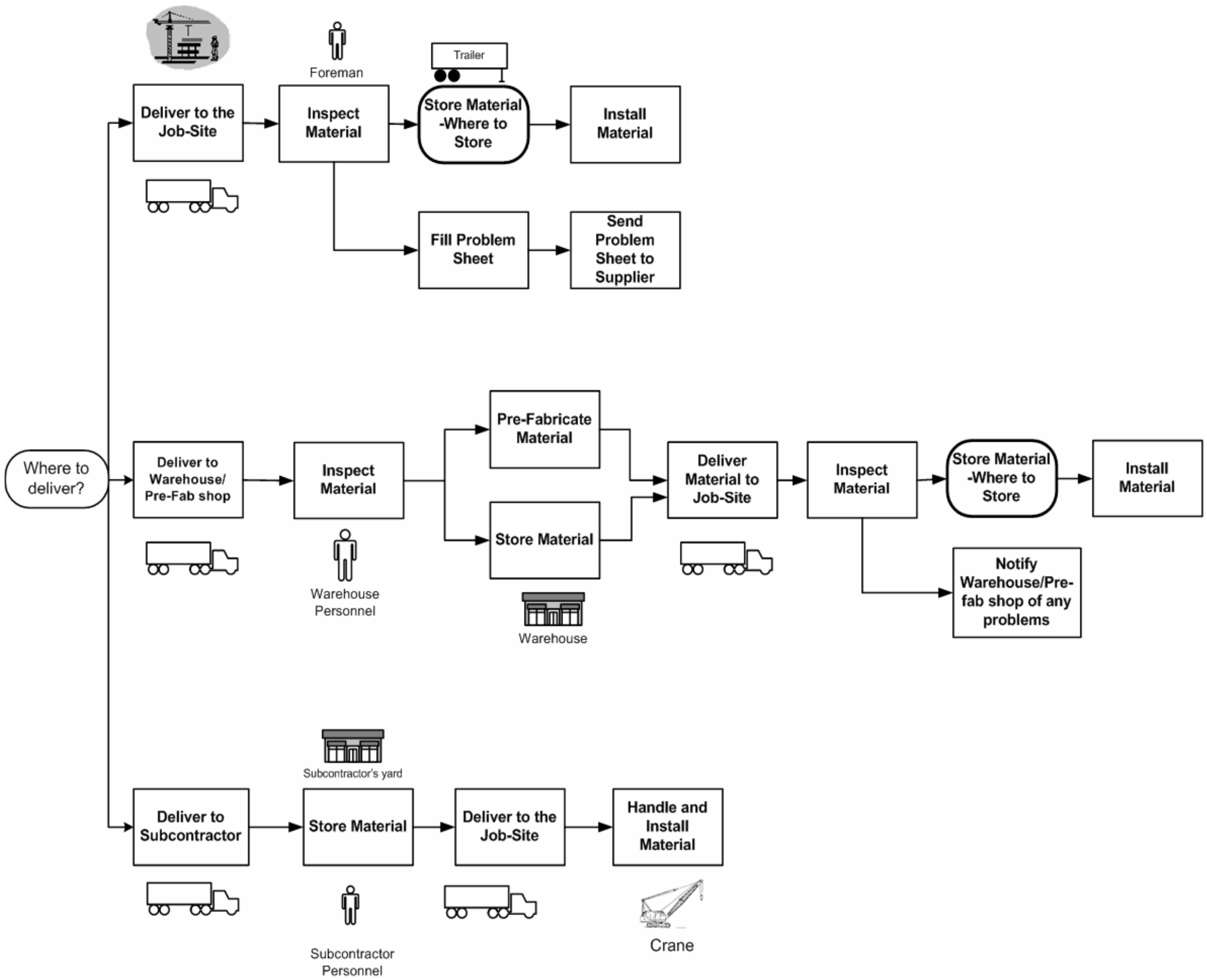

Figure 4.6: Construction Phase

The culture of the construction industry might be opposed to pre-fabrication. Some site personnel, particularly job foremen, may not favor pre-fabrication due to fear of loss of control on material and installation. Consequently, upper management in some companies have developed incentive programs to introduce site staff to the benefits of pre-fabrication and to facilitate a change of culture and acceptance of the process.

In other instances, the EC may utilize a subcontractor's yard for storage and subsequent delivery and installation. A typical example of this situation involves the use of the rigging subcontractor to store large-size materials such as transformers. In addition to being used for installation, the subcontractor provides storage space until material can be delivered to the site and installed. A further benefit to the contractor is the subcontractor's responsibility for any damage to the material stored at his/her yard. There is an additional fee that the contractor has to pay for the storage space and for the risk taken by the subcontractor with respect to material damage. There is a tradeoff between paying the fee and utilizing the contractor's own, limited storage space possibly requiring smaller, more frequent shipments. Another consideration is the subcontractor's assurance that the material will retain its quality and that it will be installed when needed.

4.5.4.1 Material Requisition Process

Material requisition problems greatly affect the construction stage and failure to manage this phase effectively could result in project disruption and possible delays due to late deliveries, stockouts due to small quantities bought, material delivered to the wrong locations, material backordered and effects in overall costs. The requisition process for miscellaneous material starts in the construction phase and is focused on how much material to buy, when to buy this material, where to deliver this material, when to deliver, which supplier to buy from, where to store on site.

The decision of how much to buy is very important to assure that the quantities needed are available and that there are no material shortages. The decision of when to buy is important to ensure that material is available when needed. The decision of where to deliver the material requires space planning and consideration of site limitations, pre-fabrication strategies, and subcontractors to be used. This decision should be made to minimize theft, loss and damage and at the same time considering availability of material when needed. The decision of when to deliver requires knowledge of the schedule and actual installation rates. The decision of which supplier to buy from depends on contract agreements, specifications and performance of the supplier. The decision on where to store on site depends on site restrictions and space availability.

Various interviews were conducted by the authors to investigate the different approaches used by the electrical contractors to request material during the construction phase. Based on literature review and interviews, the process starts with the generation of material release forms by the foreman or the project manager. In this form, the material needed, quantities and the dates when the material is needed are specified. The foreman sends the form to the project manager, who is in charge of requesting the material from the purchasing department. The purchasing department requests the material from the supplier and instructs the supplier about material type, quantities, time when the material is needed and instructions for delivery. Figure 4.7 depicts a typical material requisition process for miscellaneous material for an electrical contracting company.

(Step-1) Whenever materials are needed at the construction site, a material requisition process is initiated by site personnel (e.g. foreman or the project manager). The process involves the generation of a stock requisition form, presented in Figure 4.8. In this form, the material description, quantities needed, dates when the material is needed, and material cost codes are specified.

Other information specific to the job including personnel names and phone numbers, job address and ID, date and signatures are also included when filling the requisition form. The PM also includes a contact name and phone number of a designated site personnel in charge of receiving the material ordered when it is delivered to the site. Once the form is completed manually, the PM sends it to the purchasing department.

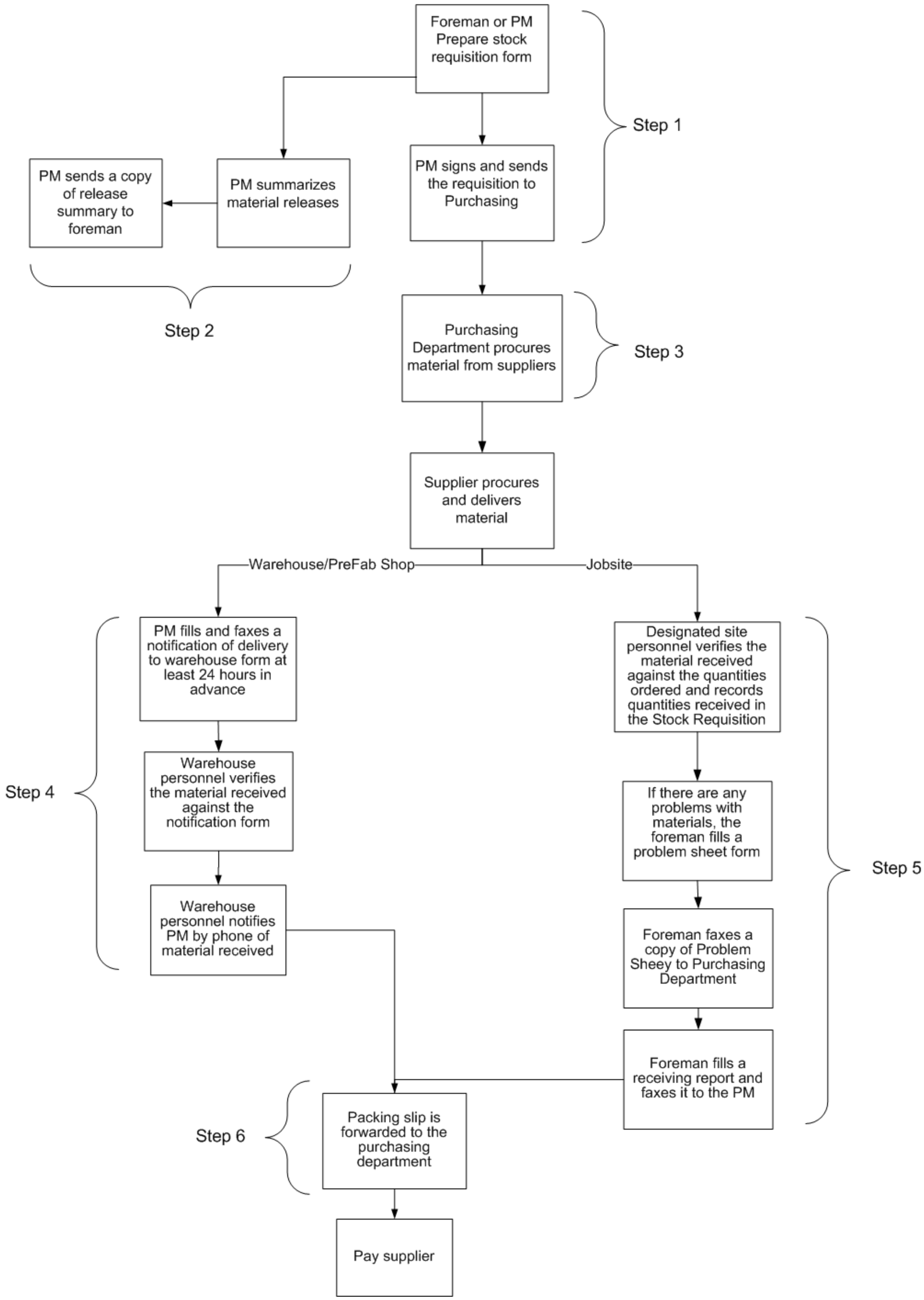

Figure 4.7: Material Requisition Process for Miscellaneous Material

STOCK REQUISITION

THIS IS **NOT** A PURCHASE ORDER

Job Name	Ordered by (Foreman)	Date
Ship to Address	Job Number	Work Order Number
	Project Manager Approval	

Item	Description	Cost Code	Quantity	Date Required	Received

Figure 4.8: Stock Requisition Form

(Step-2) The PM updates a material release summary form (Figure 4.9), based on the new order completed (Step-1). The purpose of this form is to keep records of the material being used in the project and the balance available for requisition. A copy of the summarized releases is sent to the foreman.

Material Release

Job Name	Ordered by (Foreman)	Date
Ship to Address	Job Number	
	Project Manager Approval	

Item	Quantity	Description	Cost Code	Release 1	Release 2	Release 3	Available Balance

Figure 4.9: Material Releases Summary Form

(Step-3) The purchasing department requests the material from pre-selected suppliers/vendors and instructs the supplier/vendors about material type, quantities needed, time when the material is to be delivered and instructions for delivery (i.e. location and contact person).

The purchasing department forwards a copy of Form 1 with this information to each supplier/vendor. Material is generally requested for delivery to the jobsite. Material is generally requested for delivery to the job site. In some instances this may not be feasible due to storage or access limitations. In this case, the material is delivered to other locations such as the contractor's warehouse or another subcontractor storage area. Material is delivered to a warehouse in cases such as when critical specialty items are ordered early and are not going to be installed immediately, when storage area at the job-site is unavailable, or if the material will be used for pre-fabrication. Storage of the material at the warehouse prior to moving it to the jobsite increases indirect costs due to re-handling. Some companies utilize a pre-fabrication shop facility to assemble components in a controlled environment. Advantages of pre-assembly include increased production time and reduced labor costs compared to performing the assembly process in the field where poor weather conditions and space limitations may cause work delays.

The increase in productivity and savings in labor costs out weigh additional costs encountered due to pre-fabrication and re-handling. Some site personnel, particularly job foremen, may not favor pre-fabrication due to fear of loss of control on material and installation. Upper management for some companies has developed incentive programs to introduce site staff to the benefits of pre-fabrication and to facilitate a change of culture and acceptance of the process.

In other instances, the electrical contractor may utilize a subcontractor's yard for storage and subsequent delivery and installation. A typical example of this situation involves the use of the rigging subcontractor to store large size materials such as transformers. In addition to using him for installation, the subcontractor provides available storage space until material can be delivered to the site and installed.

(Step-4) In the case that the material is delivered to the warehouse, the PM fills a notification of delivery to warehouse form (Figure 4.10) to notify the warehouse personnel that certain material will be delivered to the warehouse for storage. This form specifies the type and quantity of material to be delivered, when it will be delivered, job number, supplier/vendor's name, carrier name, and holding period for the material. This form should be prepared and sent at least 24 hours in advance of delivery. Once delivered, the warehouse personnel verify the material received against the notification of delivery to warehouse form and stamps the packing slip for acknowledgement that the material was received. The packing slip is forwarded to the purchasing department for payment purposes. If there is any damaged material, it is noted on the packing slip and the purchasing department is notified. The warehouse personnel also notifies the PM by phone of all material received and stored at the warehouse.

Notification of Delivery to Warehouse

Date ____________ Job Number ____________
PM ____________
Vendor ____________ Carrier ____________
Date of Expected Delivery ____________
Description of Packing (i.e. reels, pallets, boxes): ____________

Quantity	Description

Total Weigh of Shipment ________ pounds

Disposition of Material (i.e. ship to job, pack and hold):

____

____

Time Period to hold material ____________
*** Material will be refused if this notification is not received by the Warehouse at least 24 hours prioir to delivery
NO EXCEPTIONS!!!

Electrical Contractor

Figure 4.10: Notification of Delivery to Warehouse

(Step-5) In the case that the material is delivered to the jobsite, the designated site personnel verify the material received against the stock requisition form. Actual quantities received are recorded in the received column in the requisition form. If there are any discrepancies in material quantities, damages to material or items not delivered, the foreman fills a problem sheet form (Figure 4.11) and forwards a copy of this form to the purchasing department. At the time that the material is received, the foreman also fills a receiving report (Figure 4.12) and forwards this receiving report to the PM.

Problem Sheet
Purchasing Department

Today's Date ______ Foreman ______ Project Manager ______
Requisition # ______ Dated ______ Job Number ______
PO Number ______ Vendor ______ Ticket # ______

Stock Req Line #	Quantity Ordered	Material Description	Received	Refused	Short

Comments ______

Corrective Action Taken ______

Figure 4.11: Problem Sheet Form

Electrical Contractor

Receiving Report

PO Number	Job Number	Job Name
Shipper		

Item No.	Quantity	Description	Remarks

Figure 4.12: Receiving Report

(Step-6) For payment purposes, a copy of the packing slip is faxed to the purchasing department, from the warehouse or the site, for acknowledgment of delivery of material and payment purposes.

Figure 4.13 illustrates a summary of the information flow between the forms used in the requisition process. The stock requisition form, Figure 2, is the base form used to input information into the other forms. This information transfer between forms is done manually, which requires double entry. The process is time consuming and prone to error

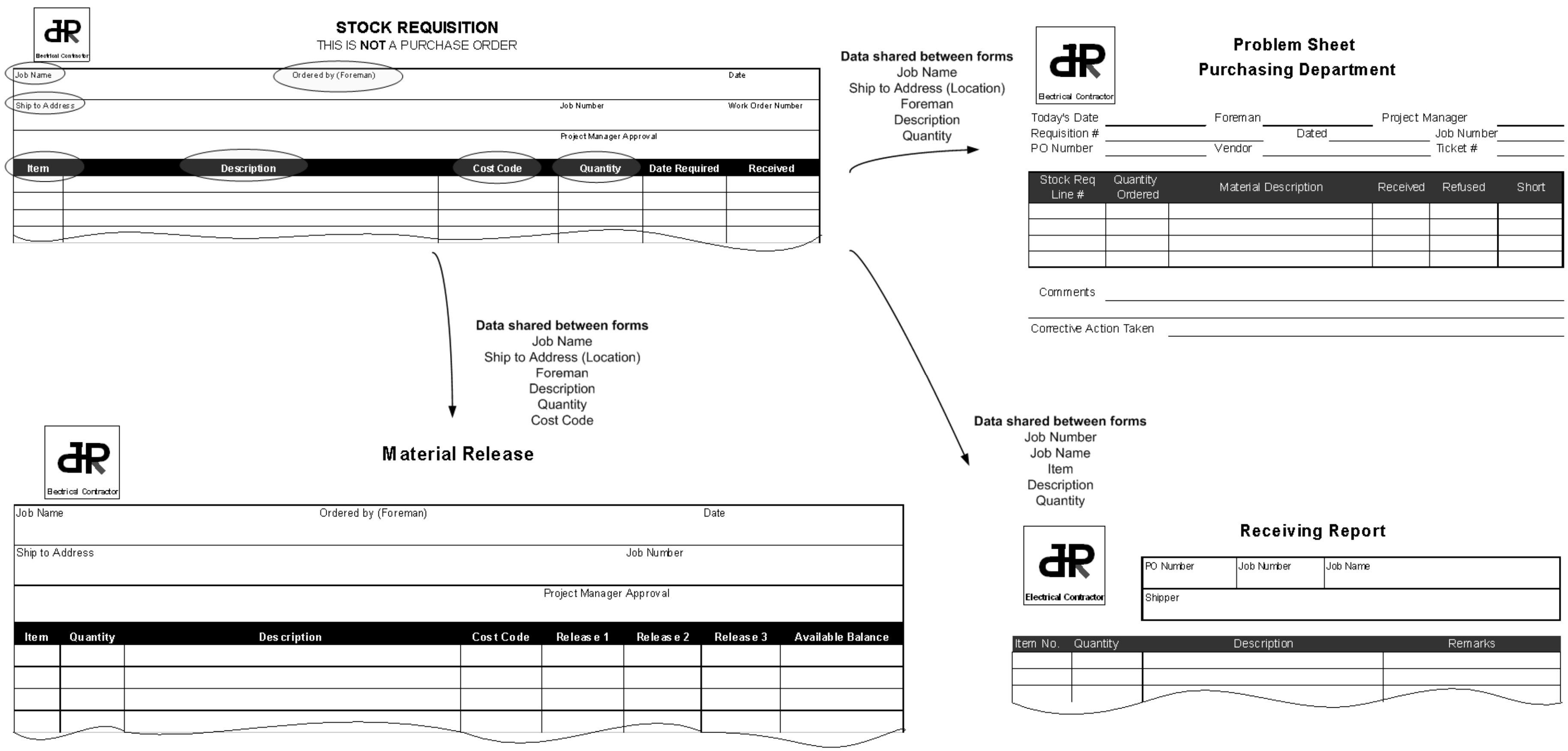

Figure 4.13: Information Flow between the Paper Forms

due to the manual input of data. From the stock requisition form, the material description and quantity requested in a particular period is input into the material release form. This form is used to keep track of the material ordered in each period and the remaining balance. If there are any problems with the material ordered (e.g. damage material, incorrect quantities) the site personnel writes the material description and the problem encountered into a problem sheet form. Most of this information is coming from the stock requisition form. When an order of material is received, a receiving form is filled. In this form, PO number, job number, job name, material description, and quantity received. All the information, except the quantity received, is obtained from the stock requisition form.

4.5.5 Phase 5: Post-Construction

After installation of the materials on the structure, the EC has to manage any surplus material. The surplus is handled differently depending on the type of material and also whether or not the contractor has a warehouse. If the company has a warehouse, the surplus material is stored in the warehouse for use in future projects. Other companies return surplus material to the supplier for reimbursement. Usually, there is no penalty or re-stocking fee for commodity items. For specialty items there is usually a 20-25% penalty. The EC has to track surplus material to avoid lost or theft. Figure 4.14 presents the post-construction phase.

An effective material management system is essential to avoid material shortages, misplacements, loss, and theft which might result in increases in crew idle times, loss of productivity and delay of activities. Electrical contractors should implement an efficient material management system due to the fact that in most of the cases they are asked to squeeze their bids in order to keep the costs of project under budget. In such a case, failures to effectively manage materials could result in decreases in profit or even a loss. The material management processes for the companies visited are very similar, although there are some differences.

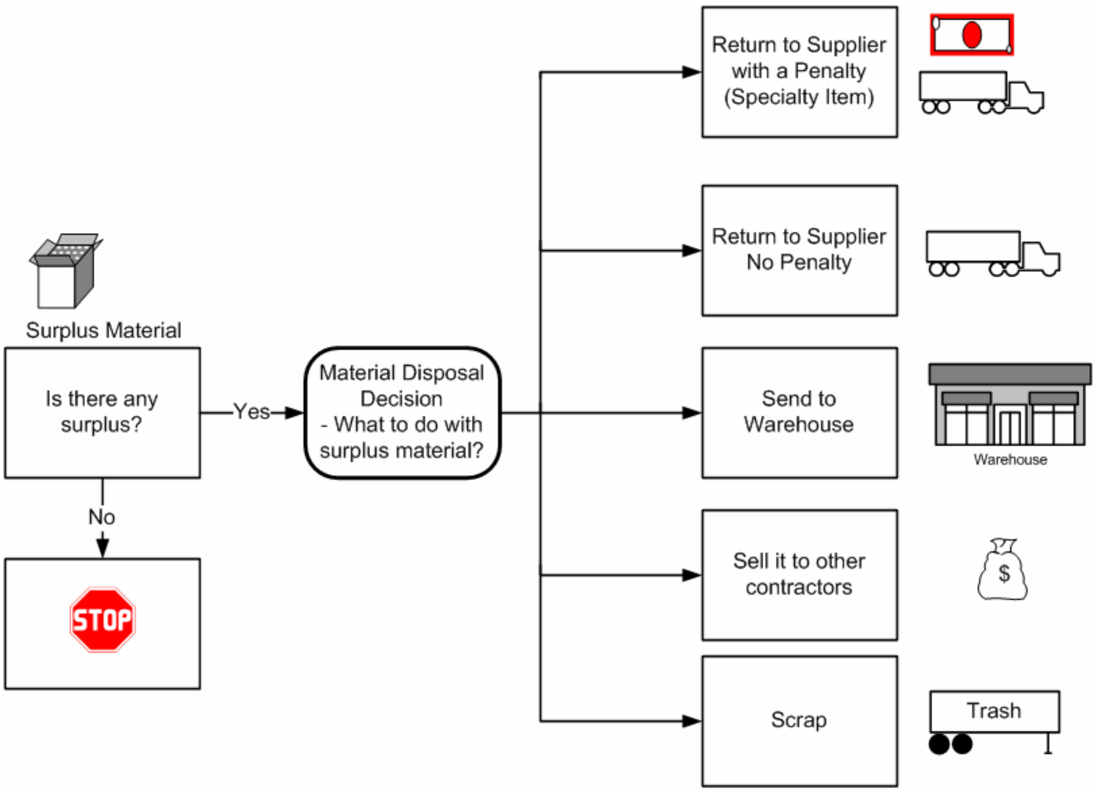

Figure 4.14: Post-Construction Phase

The primary goal for these companies is to have the material needed, in the amounts needed, with the quality required, and the time that they are needed. Based on the interviews conducted, most companies have a material management system that serves their needs, although it could be improved. Standardization of the material management system could be a step forward in improving the system for all the companies and eliminating some of the bottlenecks.

The interviews performed allowed collecting data for different contractors in the Northern Virginia (NOVA), Maryland, Virginia, North Carolina and Tennessee areas. The flowcharts presented in Figures 1-5 represent general flowcharts that describe a compilation of the current material management practices for the companies visited. Individual flowcharts for all the companies visited were prepared and these flowcharts represent the way in which every company handles their material. Figure 4.15 presents a

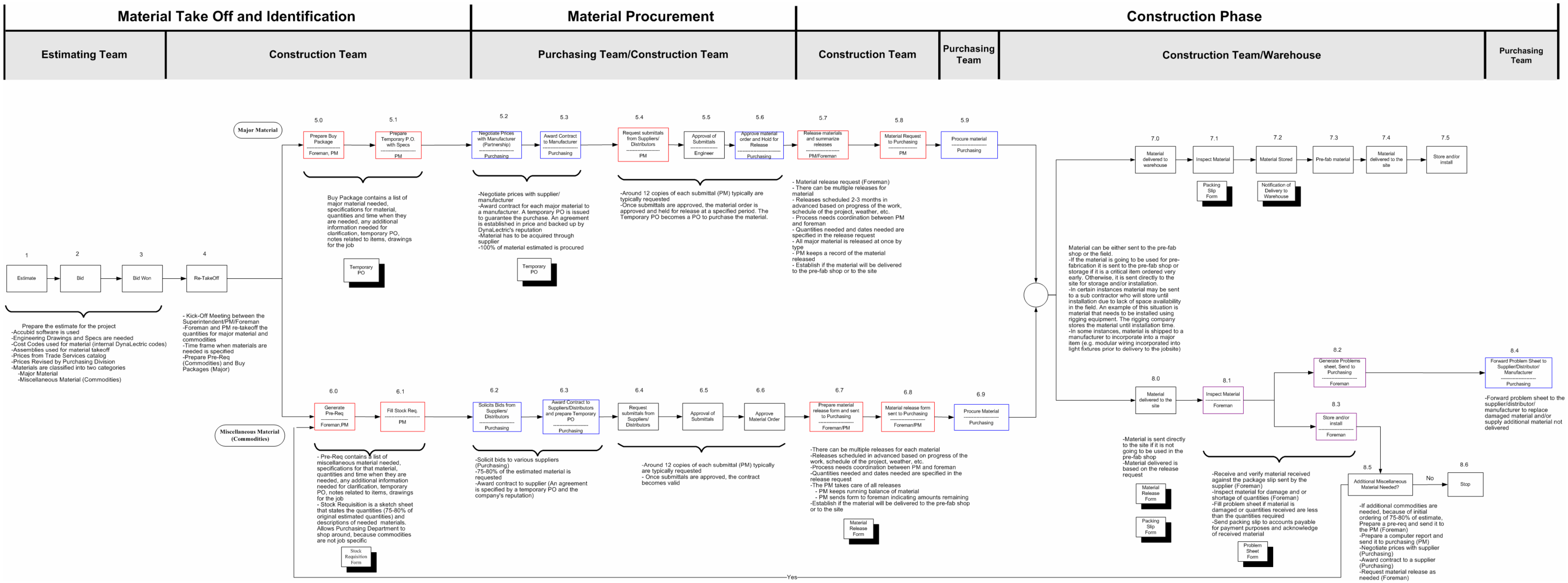

Figure 4.15: Material Management Process for Contractor A

flowchart for the material management process for Contractor A of the companies interviewed. The rest of the flowcharts developed, narratives and questionnaires from interviews can be seen in the Appendix. A narrative of their material management process follows.

This section presents a narrative of the materials management process for this company. The steps presented on the flowchart, illustrated in Figure 4.15, are described in this document. The description is based on the numbers assigned to every box on the flowchart.

1, 2, 3: Estimating, Bid Submittal, Bid Won

Prepare the estimate for the project.

- Accubid software is used
- Engineering Drawings and Specs are needed
- Cost Codes used for material (internal Contractor A codes)
- Assemblies used for material takeoff
- Prices from Trade Services catalog
- Prices Revised by Purchasing Division
- Materials are classified into two categories
    - Major Material
        - Gear- Electrical Distribution equipment
            - Panels
            - Circuit Breakers
            - Sub-stations
            - Transformers
        - Lighting fixtures
            - Chandeliers, Wall brackets
        - Systems Division – Special division that purchase this type of material

          Fire Alarms
            - Security Alarms
        - Generators- Locally generated power
            - UPS systems
            - Generators systems

- Miscellaneous Material (Commodities)
  - Bolts
  - Nuts
  - Conduit
  - Wire
  - Boxes
  - Electrical tape
  - Wire connectors
  - Electrical fittings
  - Conduit strap fasteners
  - Dimmers
  - Hanger supports
  - Elbows
  - Wiring Devices (light switches, power receptacles)

4. Re-Takeoff

- There is a Kick-Off Meeting between the Superintendent/PM/Foreman
- Foreman and PM re-takeoff the quantities for major material and commodities
- The time frame when materials are needed is specified
- Prepare Pre-Req and Buy Packages
  - Pre-Req contains a list of miscellaneous material needed, specifications for that material, quantities and time when they are needed, any additional information needed for clarification, temporary PO, notes related to items, drawings for the job
  - Buy Package contains a list of major material needed, specifications for that material, quantities and time when they are needed, any additional information needed for clarification, temporary PO, notes related to items, drawings for the job

Major Material

5.0, 5.1 Prepare Buy Package

- Quantities needed are specified

- Specifications from the engineer are included with the buy package
- Date Needed (Time Frame)
- Computer generated report (Temporary PO) sent to purchasing by PM. Scope of work not completely specified and a material list is not specified. Based on the drawing and specifications, the manufacturer provides the required material to Contractor A.

5.2, 5.3, 5.4, 5.5, 5.6

- Negotiate prices with supplier/manufacturer (Purchasing department)
- Award contract for each major material to a manufacturer
- Material has to be acquired through supplier
- 100% of material estimated is procured
- Request submittals from the manufacturer, typically around 12 copies of each submittal (PM)
- Approve submittals (Engineer)
- Once submittal is approved, the material order is approved and held for release at a specific period through a temporary PO. The temporary PO guarantees the purchase. An agreement is established in price and backed up by Contractor A's reputation

5.7, 5.8, 5.9

- Request for material release (Foreman)
  - There can be multiple releases for material
  - Releases scheduled 2-3 months in advanced based on progress of the work, schedule of the project, weather
  - Coordination between PM and foreman
  - Quantities needed and date needed are specified in the release request
- Forward material requests to purchasing (PM)
  - All major material is released at once by type
  - PM keeps a record of the material released
  - Establish if the material will be delivered to the pre-fab shop or to the site
- Request material from the supplier (Purchasing)

5.10, 5.11, 5.12, 5.13, 5.14

- If the material will not be pre-fabricated, it is sent to the construction site
- Receive and verify material received against the packing slip sent by the supplier (Foreman)
- Inspect material for damage and/or shortage of quantities (Foreman)
- Fill a problem sheet if material is damaged or quantities received are less than the quantities requested
- Send packing slip form to accounts payable for payment purposes and acknowledge of received material

Miscellaneous Material

6.0, 6.1, 6.2

- Specify quantities needed
- Specifications are included with the pre-req
- Date Needed (Time Frame)
- Fill stock requisition by hand. This form includes material and quantities needed, and estimated dates for delivery
- Generate computer form (PM). This form will be sent to the purchasing department

6.3, 6.4, 6.5, 6.6, 6.7

- Solicit bids to various suppliers (Purchasing)
- 80% of the estimated material are requested
- Award contract to supplier,
- Request submittals from suppliers, usually 12 copies (PM)
- An agreement is specified by a temporary PO and the company’s reputation
- Approve submittals (Engineer)

6.8, 6.9

- Prepare material release request form
    - There can be multiple releases for material
    - Releases scheduled in advanced based on progress of the work, schedule of the project, weather
    - Coordination between PM and foreman

    - Quantities needed and date needed are specified in the release request
- The PM takes care of all releases
    - PM keeps running balance of material
    - PM sends form to foreman indicating amounts remaining
- Send release request to purchasing (PM)
- Request material directly from supplier (Purchasing)

Decision to Make with Respects to Delivery Location

Material can be either sent to the pre-fab shop or the field.

- If the material is going to be used for pre-fabrication it is sent to the pre-fab shop or storage if it is a critical item ordered very early. Otherwise, it is sent directly to the site for storage and/or installation.
- In certain instances material may be sent to a sub contractor who will store until installation due to lack of space availability in the field. An example of this situation is material that needs to be installed using rigging equipment. The rigging company stores the material until installation time.
- In some instances, material is shipped to a manufacturer to incorporate into a major item (e.g. modular wiring incorporated into light fixtures prior to delivery to the jobsite)

7.0, 7.1, 7.2, 7.3, 7.4, 7.5

- If the material is going to be used in pre-fabrication, the material is delivered to the warehouse. In some instances, critical materials that are ordered early are stored in the warehouse until they are going to be installed.
- The material is inspected against the packing slip sent by the supplier/distributor. It is inspected for quality, quantity and to verify that the delivered material was the material that was ordered.
- Once the material is inspected, it is stored in the warehouse and a notice to delivery to warehouse is sent to the project manager to notify that the material was delivered.
- The material is used in the pre-fabrication process

- Once the pre-fabrication process is finished, the assembled material is delivered to the site when needed. The material is stored on site

8.0, 8.1, 8.2, 8.3, 8.4

  - Miscellaneous material is sent directly to the site if it is not going to be used in the pre-fab shop
  - Material delivered is based on the release request
  - Receive and verify material received against the package slip sent by the supplier (Foreman)
  - Inspect material for damage and or shortage of quantities (Foreman)
  - Fill problem sheet if material is damaged or quantities received are less than the quantities required
  - Send packing slip to accounts payable for payment purposes and acknowledge of received material Send problem sheet to purchasing department (Foreman)
  - Forward problem sheet to the supplier (Purchasing)
  - Replace damaged material and/or supply additional material not delivered (Supplier)

8.5

- If additional commodities are needed, prepare a pre-req and send it to the PM (Foreman). This is because 75-80% of the originally estimated commodities are bought.
- Prepare a computer report and send it to purchasing (PM)
- Negotiate prices with supplier (Purchasing)
- Award contract to a supplier (Purchasing)
- Request material release as needed (Foreman)

4.6 Supplier/Contractor Arrangements

Unavailability of materials when needed can greatly affect the productivity of the workforce, thus causing delays to activities, increasing the cost of the project and possibly delaying the completion of the project. There is no doubt availability of materials when needed is critical for the successful completion of the project. The contractor should search for arrangements that will ensure availability of materials when they are needed. This section presents an overview of the value added services that suppliers offer to contractors, partnering agreements between contractors and suppliers, and the benefits for the contractor when using this type of arrangements.

4.6.1 Partnering

The construction industry has been characterized by adversarial relationships between the parties involved. Traditionally, the most common way in which the contractor gets most of his projects is by hard bid. Because of the competitive nature of hard bidding, the contractor needs to obtain materials and subcontractor's services at the lowest cost possible. Usually, the contractors request bids from suppliers and subcontractors in order to get the lowest prices possible for their services and products. Suppliers or subcontractors will try to win the contract by offering a relative low price to the contractor. Sometimes the price offered might not be low enough to win the contract and the contractor could request a lower price. If the supplier or subcontractor does not lower the price, the contract might be awarded to another party. This bidding process might create adversarial relationships because the suppliers or subcontractors could get the job at a lower amount than what they originally were expecting; therefore they are making less profit. Because of this loss in profit, the supplier or subcontractor might not be totally devoted to this particular contract and some problems might arise.

The relationship of a contractor with his suppliers is critical for the successful completion of any construction project. Availability of materials is essential for the timely completion of activities and for the productivity of the labor force. If materials are not available when they are needed, a variety of problems might arise. Leenders et. al. (2002) offer a classification of supplier based on the quality of the service that the supplier offers to the customer. The classifications that they present are unacceptable suppliers, acceptable suppliers, good suppliers, preferred suppliers, and exceptional suppliers. A description of each category follows.

- Unacceptable suppliers- these suppliers are not able to meet the operational needs of the customer and are not able to provide materials when they are needed. In addition, they don't offer means to satisfy the strategic needs of their customers.
- Acceptable suppliers- these suppliers meet the current operational needs of the customer, however, the services that they provide can easily be matched by any other supplier.

- Good suppliers- these suppliers are a step above acceptable suppliers in the fact that they can provide the materials needed, but in addition they can also provide some value added services.
- Preferred suppliers- these suppliers offer a system that integrates the buying/selling functions in an electronic format. This integration eliminates duplication and allows to process transactions faster. These suppliers meet both the operational needs of the company as well as their strategic needs.
- Exceptional suppliers- these suppliers are able to recognize and anticipate the needs of their customers and are able to satisfy those needs. Because of the value they provide to their customers, they are valued. They allow customers to experiment with different scenarios and approaches, because of their efficiency, which results in minimization of risk for their customers.

To minimize the risk of not having materials when they are needed, companies are recurring to set up partnering agreements with suppliers. A partnering agreement is a business relationship that looks forward to the benefits of the partners involved. A partnering agreement does not represent a legal partnership with the associated partners, instead it refers to an informal working agreement to maintain cooperative relationships. In such types of agreement, the decision process should be done in a win-win basis for all the parties involved. No benefits should be acquired by hiding information from other parties. A successful partnering relationship consists of trust, fairness and commitment from all the parties involved. Communication is a very important aspect in Partnering. Open and honest communication among team members is critical.

Leenders et. al. (2002) describe two different types of partners, basic and extended partners. They point out that all suppliers should be treated as basic partners with respect among parties, honesty, trust, open communication, and understanding of the aspects that drive their relationship. An extended partnership is only established with key suppliers. This type of agreement goes beyond basic partnering and is oriented on the goals of the supplier and customer. It is not uncommon to have a team, comprised from supplier/customer employees, to create plans for mutual success and profitability. Extended partnering has a long term view and improvement of both parties should be the main objective.

Anderson (1994) defines some key elements of a Partnering agreement. A brief description of these elements follows.

- Commitment -All members of the team should commit to good faith and fair dealings with the other partners
- Equity- When developing mutual goals and plans for the companies, the interest of the stakeholders must be considered. If there are aspects that stakeholders don't appreciate or think that are valuable, they won't commit to the partnership agreement.
- Communication- Open and honest communication is critical.
- Trust- Trust is critical for resolution of issues. Information sharing among partners without fear is essential.
- Issue Resolution System- There most be a fair process for dispute resolution without finger pointing. These issues should be solved quickly and in a fair way.
- Evaluation- Meetings are needed to evaluate the work being performed by the team. An assessment of work performed vs. work accomplished is essential to identify if the partnership agreement is working as expected.

4.6.1.1 Benefits of Partnering

One of the biggest benefits of a Partnering agreement is the elimination of adversarial relationships between contractors and suppliers. The cooperative environment between the parties minimizes the risk of unavailability of materials on the construction site when they are needed. In addition, the contractor will ensure that bills are paid as stated in the partnership agreement, which provides a better cash flow for the supplier. Another main benefit is the information sharing between parties, which can lead to the enhancement of one company's competitive position by using the information and resources provided by the partner company.

4.6.1.2 Concerns with Partnering

One of the biggest concerns with Partnering comes from the supplier side. Some suppliers feel that they can gain more benefits if they continue in the competition based environment. Suppliers don't want to change the procurement tools and techniques that they have been used for a competitive environment (Leenders et. al., 2002). A change to a partnership type of agreement will require the revision of their current procurement tools and techniques. Some of the suppliers might argue that some companies might try to take advantage of the partnership and their preferred status, a situation that can create problems among partners. Another aspect that brings concerns is the intellectual rights for new technology developed by these partners. A critical aspect deals with the fact that sometimes there is a doubt on how far a partner can be trusted for information sharing purposes. There is always the feeling that this information might end in the competitor's desk, which could seriously harm the competitive edge of the company.

4.6.2 Value Added Services

Typically the supplier/distributor is viewed by the electrical contractor only as the source that supplies the materials needed for the construction of the project. Many suppliers are looking for ways to survive in a market full of suppliers. These days it is difficult for a supplier to compete in the market based on product price alone, therefore suppliers are looking for other ways to generate income by providing additional services to their customers. These services are known as Value Added Services (VAS). Some of the benefits that a customer can expect when receiving supplier value added services include:

- Quality – the supplier will ensure that the contractor will receive defect free materials
- Timely deliveries - supplier will ensure timely delivery of materials
- Continuity of supply – the supplier will ensure supply of materials as needed to reduce risk of shortages of materials

The services provided by the supplier can range from testing of materials to inventory management. Services provided by the supplier include:

- Training of employees
- Testing of materials
- Inventory management
- Bar coding services
- Financing
- Availability of materials from different manufacturers
- Competitive prices

- Bill of material ordering
- Invoice statement and faxing
- Customized delivery service

These and other services will be described in the following sections.

Access to products

The distributor offers a variety of products from different manufacturers. This helps the contractor to compare and select the materials by just visiting one place and by comparing prices, availability and quality.

Training of Employees

Suppliers can provide training to customer's workforce on how to install components. This is a beneficial tool to improve workforce knowledge on the product, thus increasing productivity and lowering the time required to install them.

Testing of Materials

The supplier can test power equipment and other equipment before delivering to the site. This will eliminate deliveries of defective equipment, which will eliminate the time and cost required to send that equipment back to the supplier. In addition, the supplier could calibrate the equipment to the levels specified after doing the testing.

Bar coding

By using bar codes, the supplier can ensure fast and accurate handling. With bar codes attached to particular equipment, information about that particular equipment can be provided instantly by scanning the bar code. Incoming goods can be count directly and manual entry errors are avoided. Materials used can be scanned and inventories can be kept easier and almost in real time, once the material is scanned and the information sent to the inventory database.

Vendor Managed Inventory (VMI)

The supplier/distributor can provide the contractor with relative fast access to equipment and materials needed. The contractor does not need to have an extensive inventory on the construction site and/or warehouse. These VMI services can be provided in two ways: the supplier can provide a trailer on site and/or the supplier can provide yearly contracts for miscellaneous materials.

- **Trailer on Site**

  The supplier buys a trailer and provides it with material ordered by the contractor in it. The contractor buys all the material in the truck and the supplier manages the inventory on the truck throughout the duration of the project. The supplier bills the contractor for materials used at predetermined prices. Once the job finishes, the contractor returns the remaining material and receives a credit from the supplier.

- **Yearly Contracts**

  The supplier can agree on a yearly contract with the contractor. This yearly contract guarantees price, availability and delivery of materials when the contractor needs them. These yearly contracts reduce the contractor's risk of being out of materials. These yearly contracts could have two forms; fixed price or fixed profit. In a fixed price contract, the supplier sells materials to the contractor at a predetermined price for an entire year. In a fixed profit contract the item is sold at the cost in that particular day plus the profit specified in the yearly contract. These contracts provide market share for the supplier. Yearly contracts are not used for major items such as switch gears, fixtures. Suppliers can't fix the price of commodities such as wires and PVC piping, because their price is dependent on market conditions.

Technical expertise and information

The distributor/supplier can assist the contractor in designing power, communications, and control systems. The supplier can also serve as a contact point with the manufacturer in case that the manufacturer's assistance is needed in the performance of lighting design, short-circuit analysis and other devices coordination studies, or any other design assistance.

Short Term Financing

The supplier/distributor provides the contractor with credit, usually 30 days, when the contractor buys materials. This service provides a better cash flow for the contractor and reduces the use of the line of credit.

Competitive Prices

There is an excess of suppliers/distributors in the market. Suppliers are always looking for ways to stay competitive in the market. The competition among distributors is beneficial for the contractor, since he can get better prices as opposed to a market in which there is only one supplier. Sometimes when suppliers have good relations with contractors, they usually offer good prices to these contractors.

Customized delivery service

Supplier can offer deliveries that meet the requisites of the contractor. In addition, suppliers can provide free delivery services to local areas. This represent cost savings for the contractor. Suppliers could also provide Just In Time deliveries, which minimize the storage needed by the contractor.

Invoice statement and faxing

Some suppliers provide overnight transmittal of invoices of daily purchases. This service allows the contractor to keep records of daily expenses. In addition, the contractor knows how much he has to pay to that particular supplier on the specified paying day.

Bill of material ordering

With this service, the supplier can consolidate invoices on a daily or weekly basis. These invoices can be sent electronically to the contractor. All invoices can be converted into a single invoice that contains all the purchase orders for that particular period of time.

Kitting

Kitting refers to a part that is comprised of components from different manufacturers, but has been assembled by the supplier and only one part number has been assigned to the assembled part. This makes it easier for the contractor, because if the contractor is going to assemble the part by himself, he has to know the part numbers for all the components of the part. In addition, there are savings on the time required to assemble the part.

Invoice consolidation

Invoice consolidation is used when a contractor wants to pay the bill on a specific day rather than paying for materials as they are received on the jobsite. By using the invoice consolidation service, the contractor only makes a monthly payment to the supplier instead of making several payments during a particular month.

Interactive Quote System

This service allows the contractor to obtain immediate prices and information on the availability of the material. The contractor saves time, because he can get this information by just sending a quote to the supplier by fax, instead of visiting the store in person to check for availability and price for the materials.

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CHAPTER FIVE: MATERIALS MANAGEMENT CHALLENGES IN CURRENT PRACTICES

In the competitive environment in the construction industry, it is critical for the contractor to focus all the energies in the efficient and effective execution of the all the activities involved in construction. This effort requires the preparation of a plan to delineate the sequence of activities. Some of the resources needed to perform the activities include materials, equipment and labor. In the electrical contracting industry, material ordering and delivery are very critical to the successful execution and completion of any project. Special attention should be placed in dealing with the activities related to materials. Furthermore, the contractor needs to anticipate possible problems and provide possible solutions so that the project would not be affected in the case that problems arise. This section will identify problematic issues or challenges in the material management process for an electrical contractor.

Many challenges are encountered during the five phases of the materials management process. These challenges were grouped into three categories: information technology, decision modeling and implementation management.

5.1 Challenges – Information Technology

Figures 4.3 to 4.6 and Figure 4.14 illustrate numerous exchanges of information within the five phases of the materials management process. Hence, the efficient operation of the materials management process depends on accurate and timely generation and transfer of information. Not all information that is necessary for the smooth operation of materials management is computerized, but it is safe to say that computerized and networked information systems offer speed, accuracy and retention of information that few contractors can afford to forego. Some examples of the critical role of advanced information technology within the materials management process are presented in the following sections.

During the Bidding Phase, the GC may be forced to cut costs to satisfy budget limits of owners while still committing to the same scope of work. The EC is usually one of the last trades to be procured in a project and many times is asked by the GC, prior to finalizing the sub-contract agreement, to absorb some of these cost reductions. This puts pressure on the EC to complete the scope of work for a lower cost than what was initially budgeted. This situation usually arises because the GC promises unrealistic estimates to the owner without the direct involvement of his specialty contractors. The problem could be minimized if the EC is involved in the pre-construction planning and design phase of the project (see Figure 4.3).

The EC can provide to the owner expertise regarding materials and means and methods for installation, as well as more realistic cost estimates. The EC could also provide information about the difficulty, cost and time required for installation in order to better assess the effect that the changes in scope could have on overall cost and schedule. The enabling technology for such integration of the EC in the project's bid estimation is internet-based communications between the GC and the EC and the electrical contractor's access to a database of material prices, lead times, wage rates and standard job times.

The Sourcing Phase requires access to data regarding prices, quality, delivery performance and existing contractual arrangements with manufacturers and suppliers. Typically, prices are requested by a fax transmittal from the EC to the potential suppliers. Fax technology is becoming more time consuming compared to other recent means of data communication. Fax machines are also more prone to breakdown problems (e.g. paper jams, incomplete transmittal, etc.) compared to other methods (e.g. computers). Furthermore, it could take longer for the fax information to reach the person in charge of providing quotes and for the EC to get an answer to the request for pricing. There have been some efforts to develop a P2P network pricing system that will allow ECs' personnel to have immediate access to the current prices of a particular supplier with near real-time updates, therefore reducing the difficulties that the current practice presents. Ideally, the EC would be able to draw on historical data reflecting experience with different supply sources as well as up-to-date pricing and delivery data. Clearly, a combination of on-line and proprietary data is required.

The Procurement Phase integrates individual orders, shipments and deliveries with the contractor's materials management plan. The person in charge of procuring material or the purchasing department, in the case of a large company, needs to ensure that the correct material in the correct quantities is ordered. This person also needs to verify the dates at which the material is needed and clearly indicate to the supplier where to deliver the material. Ready access to contract data and project scheduling data as well as a means to communicate delivery instructions to personnel on site is essential to performing these tasks. Material is usually procured by a fax transmittal from the EC to the supplier indicating the material needed, quantities and delivery dates. This process might present the same challenges that are present in the sourcing phase. Similar to the sourcing phase, there have been efforts to develop a P2P network that will allow the EC to place orders through a computer. This will accelerate the ordering process and reduce errors that often occur in current practice.

During the Construction Phase and the Post-Construction Phase tracking material is one of the biggest challenges faced by the electrical contractor. Tracking allows for identifying material not delivered as ordered or if the order was delayed. Tracking is also essential to identify what material is available, to minimize theft or loss, to identify where the material is stored on site and to control inventory costs. In some instances suppliers may deliver wrong material that need to be returned. Design changes may also result in a reduction in requirements for some material and an increase for others, which will also affect the delivery schedule. There is no direct cost to the EC when design changes are made; however, indirect costs are incurred due to possible delays associated with completing corresponding activities and possibly the overall duration of the project. In other instances, material is misplaced or relocated by warehouse personnel or is not properly identified before storage. Material that is lost, damaged or stolen after it is issued is another challenge faced by the EC that is related to material tracking. If the material is damaged during delivery and the person receiving the material acknowledges the damage, the material is returned at no cost for the electrical contractor. However, this might cause a delay if the material is needed immediately. If the person receiving the material does not verify the material and/or does not identify any damage, the contractor may end up responsible for the damaged material, which will result in a loss. Similarly, the contractor assumes responsibility for damages to material while it is stored prior to installation. An automated system, such as bar codes, could greatly improve tracking and inventory control and could minimize lost and misplacement of materials.

5.2 Challenges -- Decision Modeling

There are a number of managerial decisions that create and regulate the supply chain and are embedded in the five-phase process for materials management that is described in the previous sections. In Figures 4.3 to 4.6 and Figure 4.14 those junctures or nodes in the materials-management process that constitute decisions are identified by means of rounded rectangles. Table 5.1 offers a consolidated list of these decisions and the elements of each decision in terms of alternatives, parameters, and performance measures.

Decision	Alternatives	Parameters	Performance Measures
What is the EC's bid price?	• Contract bid price • Reject bid request	• Project specifications • Project schedule	• Expected contract profit • Financial risk

Table 5.1a: Bidding Phase Decision

Decision	Alternatives	Parameters	Performance Measures
What type of material to buy?	• Major material • Commodities • Consumables	• Project specifications • Project schedule • Foreman's habits/practices • Production and usage • Needed vs. wanted	• On site availability • Purchase cost • Alternative use • Suitability
Award supplier/manufacturer contracts.	• Local suppliers • Non-local suppliers • Vendor Managed Inventory • Manufacturers	• Arrangements with suppliers • Availability • Criticality • Location of supplier • Location of project • Supplier's performance • Discounts	• Projected shortages • Inventory • Quality • Quantities

Table 5.1b: Sourcing Phase Decisions

Decision	Alternatives	Parameters	Performance Measures
When to buy material?	• 3 months in advance • 1 month in advance • 1 week in advance • 1 day in advance • Same day	• Type of material (commodity vs. major) • Project schedule • Uncertainty in project schedule • Storage Capacity • Location of the project • Location of the supplier • Criticality of the material • Order to install vs. order to pre-fab • Supplier's performance and ability to meet schedules	• Projected shortages • Inventory • Direct costs • Indirect costs
How much to order?	• As estimated • Less than estimated • More than estimated	• Project schedule • Uncertainty in project schedule • Storage capacity • Installation rate and usage • Procurement cost rates • Indirect cost rates • Discounts	• Surplus • Projected shortages • Indirect costs
When to deliver?	• Single or multiple shipments • Shipment quantities	• Project schedule • Uncertainty in project schedule • Storage capacity • Installation rate and usage • Procurement cost rates • Indirect cost rates	• Surplus • Projected shortages • Indirect costs

Table 5.1c: Procurement Phase Decisions

Decision	Alternatives	Parameters	Performance Measures
Where to deliver?	• Jobsite • Warehouse/Pre-fab shop • Subcontractor	• Project schedule • Uncertainty in project schedule • Storage capacity • Immediate	• Projected shortages • Quality • Quantity • Costs

		installation vs. critical item not be installed immediately • To be used in pre-fab or not • Costs • Location of the project • Location of the warehouse	
Where on site to store?	• "Sea cans" • on floor inside the building	• on floor space available • schedule	• loss • theft • damage • re-handling

Table 5.1d: Construction Phase Decisions

Decision	Alternatives	Parameters	Performance Measures
What to do with surplus material?	• Return to the supplier with penalty • Return to the supplier with no penalty • Send it to the warehouse • Sell it to other contractors • Scrap it	• Space availability in warehouse • Expected need for the material in future projects • Actual need for the material in an existing project	• Projected shortages • Inventory costs • Damage • Penalty costs • Opportunity costs

Table 5.1e: Post- Construction Phase Decisions

During the Bidding Phase various decisions need to be made regarding bidding and estimating the job. The first decision faced by the EC is the contract price to enter as a bid. The quantity takeoff and estimate need to be completed in order to prepare and submit a bid package to the owner. These data must be evaluated in light of the contractor's commitments on existing contracts as well as the contractor's required profit margin and tolerance of financial risk. The tradeoff presented to the contractor by this decision and the complex influences of numerous contract parameters makes the decision of how much to bid an overwhelming task without the aid of the quantitative analysis offered by a decision model.

During the Sourcing Phase, the contractor has to decide between entering into a blanket contract or a competitive bidding approach. Although guaranteed availability is insured through a blanket contract, better prices could be realized through a competitive bidding process. In addition, the contractor has to decide which suppliers are the most qualified to satisfy the conditions and services under a contract. The tradeoff between the performance measures of availability and cost and their subsequent impact on job activities and project delays need to be analyzed.

Once the Procurement Phase is underway, the contractor needs to decide how much material is needed, and when the material should be delivered to the site. The decision of how much to buy is very important to assure that material quantities needed are available and that there are no material shortages. Typically, contractors purchase an amount of material that is less than the amount estimated (e.g., 80% of original estimated material needed) in order to avoid material surplus at the jobsite. Additional quantities are purchased when the job is near completion and a better estimate is realized. This approach to materials management highlights the contractors' need for information systems and decision analysis. The cost of surplus materials is traded off against the costs of extra shipments and the risk of material shortages and ensuing project delays. Furthermore, a miscellaneous item may be used on more than one project providing the contractor an opportunity to trade off inventory holding costs with purchase costs and shipping costs by combining requirements into larger, batch shipments. Quantitative analysis of this tradeoff and obtaining the most accurate forecasts of material needs are required for optimizing the extent of deferred material purchases.

Once the construction phase has started, the decision of timing deliveries of material is based on a baseline project schedule indicating the amount of material needed at different times in the schedule, as well as anticipated productivity and past performance. From our interviews of contractors, it was found that most of the electrical contractors deliver large amounts of their material early in the project schedule based on field-personnel purchase requests without planning deliveries with respect to material needs. The decision of the timing deliveries strikes up a tradeoff between receiving materials early and incurring storage costs and not having materials on the construction site when needed. Furthermore, space constraints at the jobsite that could be critical for storage purposes are usually not considered by contractors in scheduling material delivery early in the project. This practice results in additional costs associated with storage fees, damage during storage, theft and re-handling due to space limitations. Ideally, the contractor integrates the material release schedule with the work schedule. A decision model could project space availability for every alternative delivery schedule that the contractor would like to consider. If space availability becomes a critical issue, the cost of various means of storage (e.g. “sea cans” or offsite storage locations) can be evaluated based on different factors including distance from the jobsite and associate costs.

The decision of where to deliver the material requires space planning and consideration of site limitations, pre-fabrication strategies, and subcontractors to be used. Material is generally requested for delivery to the job site. From our site visits to some projects, it was observed that in many instances the material was stored in “sea cans” located far away from the jobsite. This increases the potential of material loss due to theft. Regarding material stored in the work area, this was done without proper planning, and material often needs to be moved to free space so that other trades can work in the area. The costs associated with re-handling, loss and/or theft are not realized when ordering the material. The EC could use better procurement policies to avoid having over-stocking of inventory on the jobsite, and to decrease inventory costs. However, the effort of changing ordering policies will require a commitment of delivery when needed by the supplier. Another approach that could be used to decrease inventory is called vendor-managed inventory (VMI), described in Chapter 4. When this approach is used, the distributor places a trailer on site with the needed material and equipment and takes the responsibility of maintaining the inventory throughout the project. The distributor charges the contractor for material and equipment used at predetermined prices. At the end of the project, the distributor removes the trailer along with the unused inventory. The company can also outsource their warehouse operation to the distributor. Each of these many options for locating material storage incurs several costs and affect the risk of material shortages differently. A decision model could support a quantitative analysis of these alternatives.

Once the construction phase is completed, the decision of what to do with the surplus material depends on many factors such as availability of a warehouse and storage space, expected need for the material in future projects, actual need for the material in an existing project, inventory holding costs, opportunity costs due to having capital invested in material that is being stocked, among other factors. The EC needs to decide between sending the surplus to the supplier (a penalty cost might be incurred for specialty items), selling the material to other contractors, sending the material to the warehouse or scrapping. The decision taken depends heavily on the tradeoffs between cost savings from making material readily available versus holding costs.

5.3 Challenges - Implementation Management

Changing procedures, installing and using new information technology and elevating managerial practices to the point where decision models are in everyday use has been known to be stressful to organizations that pursue such improvements. In many cases, the inability of the organization to embrace such changes dooms the improvement initiatives. A simple example of the how improvements can be threatened by resistance to change can be found in the use of pre-fabrication shops by some contractors to assemble components in a controlled environment. Advantages of pre-assembly include increased production time and reduced labor costs compared to performing the assembly process in the field where poor weather conditions and space limitations may cause work delays. The increase in productivity and savings in labor costs out weigh additional costs encountered due to pre-fabrication and re-handling. Some site personnel, particularly job foremen, may not favor pre-fabrication due to fear of loss of control on material and installation. Upper management for some companies has developed incentive programs to introduce site staff to the benefits of pre-fabrication and to facilitate a change of culture and acceptance of the process.

Better materials management practices and decision-making models could increase efficiency in operations and reduce overall costs. Increasing pressures on project costs and completion times are motivating the need to make supply-chain decisions in a coordinated fashion and in consideration of minimizing total supply-chain cost without causing shortages. The next chapter will describe the use of decision-modeling techniques to design a framework for an integrated system of decision support for material procurement for the electrical contractor.

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CHAPTER SIX: DECISION MODELING APPROACH

Decision analysis can be defined as a methodical approach to decision making that allows managers to handle problems where different alternatives and/or a certain degree of uncertainty are involved. Decision analysis overlaps operations research and statistics that has the purpose to model and analyzing decisions made by decision makers. The objective purpose of decision analysis is to assist decision makers in making better decisions. Options are essential for decision analysis, because if only one option is available, there is no choice to make, thus no decision (Cooke and Slack, 1984). Clemen (1996) argues that the steps in decision analysis are the following: identification of the decision and objectives, identification of alternatives, modeling the problem structure, choosing the better alternative, sensitivity analysis, if further analysis is not needed, then implement the chosen idea. He states that the decision analysis process is iterative and what-if scenarios should be considered. Decision making is the process of making a selective judgement when presented with different alternatives consisting of several decision variables, and often defining a course of action. Decision making studies the identification and selection of alternatives based on the values and preferences of the decision maker. When a decision is made, it is implied that there are different alternative choices that are considered, and the decision maker wants to choose the one that best fits with his goals and objectives (Harris, 1998). Oglesby et *al* (1989) and Heller (1998) state that decision making involves three different steps: identification of the decision to be made, seeking out feasible alternatives, and choosing the most suitable alternative.

Models are representations, with assumptions, of our interpretation of reality and not reality itself. This representation should include the relevant aspects of the process being modeled. Models therefore illustrate simplifications of more complex real situations and/or processes. Decision modeling attempts to develop a model of the decision process used to make important decisions. A decision model is an analytical tool, usually in the form of a computer application, that assists a decision maker in estimating the outcomes of different alternatives and quantifying the tradeoffs inherent in choosing one alternative over another. This modeling approach presumes that a number of different factors are considered when comparing various alternatives. In addition, in such type of analysis, some of the factors could have more impact than others. The decision maker weighs the effects of each parameter on the different alternatives. Based on the judging of the importance of the effect of the parameters, the decision maker chooses the "best" alternative (The Futures Group, 1994).

Decision models are ever-present in the materials management processes of industries other than construction and have proven their worth in improving productivity and profitability. Fundamentally, a decision model describes quantitatively the cause-effect relationship between two sets of causative factors and the set of evaluative measures that the decision maker uses in order to judge the desirability of each alternative. The causative factors are divided into two sets. The controllable factors are those that constitute the alternatives or decision variables. The un-controllable factors are called parameters and must be measured, estimated or forecasted. The evaluative measures are called performance measures because they quantify the "performance" of each decision alternative.

6.1 Modeling Approach Used

Chapter 1 introduced the problem statement and the objective of this research work, which is mainly to use decision-modeling techniques to develop an integrated system of decision support for material procurement for the electrical contractor. A computer program or algorithm that performs the calculation of performance measures for each alternative is called a descriptive model because it only describes a cause-effect relationship without making any judgement about the desirability of each alternative. This judgement is left to the decision maker. The decision model at any decision node will be as depicted in Figure 6.1. The factors (or parameters) and alternatives define the inputs. Performance measures define the output.

Alternatives represent the different courses of action that a decision maker could exercise for a particular decision node or possibilities from where the decision maker chooses. Parameters represent "values" that affect the decision making process. A parameter could remain constant throughout the analysis or could be an uncontrollable variable. Uncontrollable variables refer to those parts of the decision that although having an effect in the decision taken, is not controlled by the decision maker; its values are given by factors external to the model.

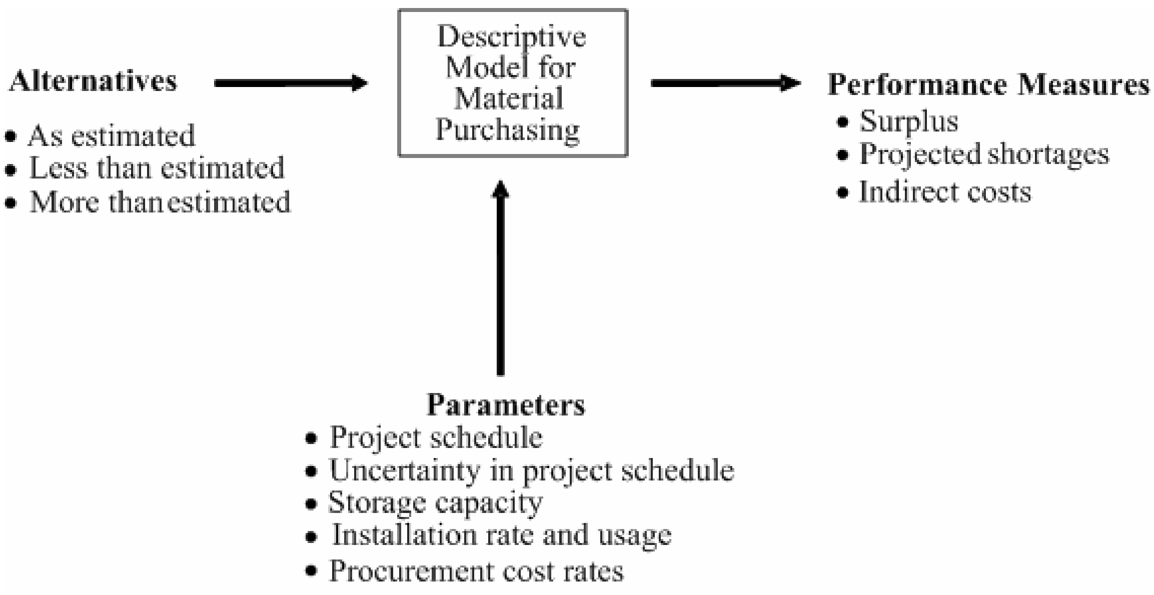

Figure 6.1: Framework for Decision Models

An example of an uncontrollable factor could be the level of demand when deciding how much production to allocate to a new product. In reality, many parameters that affect the decision making process are variable, however they are treated as constant. This assumption is part of the simplification that characterizes decision modeling processes (Cooke and Slack, 1984). Parameters must be satisfied while selecting an alternative and are critical data to be considered in the analysis since they could have a great impact in the decision making process.

The identification of model parameters could be time consuming and tedious since they are related to many areas such as project schedule, suppliers, and storage, among others, and they have to be filtered from unstructured records. As part of the research, a classification system for the model parameters was developed. This system allows classifying the model parameters into different categories. The system will be discussed in detail in Chapter 8. Performance measures are measures of the result of taking a particular alternative. They are used to measure the effectiveness of the decision taken with the alternatives and parameters used as inputs. Figure 6.1 is a schematic representation of the decision model for choosing the order quantity of an item that illustrates how such a computer program would be designed.

Some decision models go further than describing the outcomes of each alternative by determining the better choice from among all of the alternatives. These kinds of models are called prescriptive models and embody a search routine that a computer uses to carry out an intelligent, restricted trial-and-error search for the better solution. Prescriptive models leverage the decision maker by evaluating tradeoffs that are too complex or numerous for human judgement to comprehend. Figure 6.2 depicts the structure of a prescriptive model. This prescriptive model is used in the framework for the decision models in Chapter 7 to assist the user in decision making.

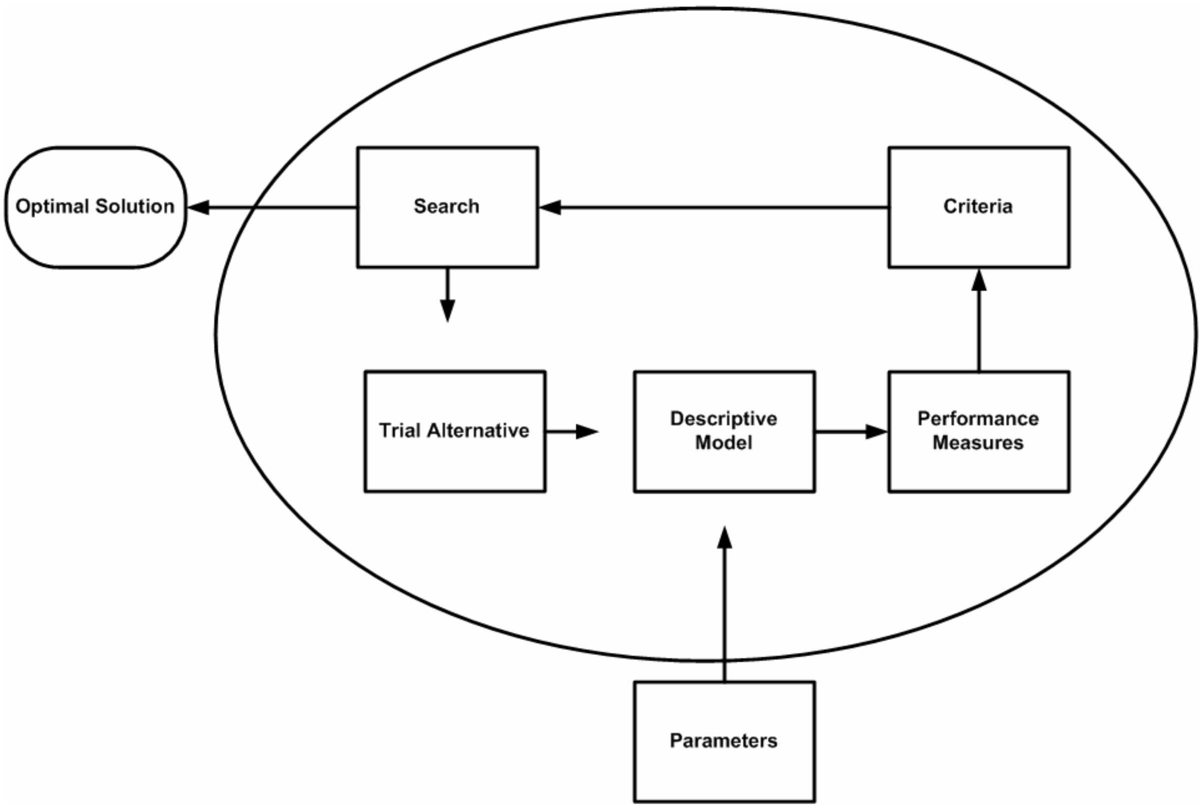

Figure 6.2: Structure of Prescriptive Model

For example, a descriptive model could be used when a company needs to decide on how much material to order. Decision alternatives might include ordering material as estimated, order less material than estimated, order more material than estimated, order material based on actual quantity or order the quantity calculated with the EOQ model. Examples of parameters might include the storage capacity, availability of space, location of the job, discounts, progress of the work. Examples of performance measures might include shortages, surplus of material. Based on the information input (i.e. alternatives and the parameters), an analysis will be performed to assist the electrical contractor with the amount of material that should be acquired.

If a prescriptive model is used or if enough trial solutions are tested using a descriptive model, a better solution can be produced. However, a model is only an approximation of the real world and decision makers usually modify the better solution based on factors and performance measures that are not included in the model. This final step produces the planned solution. Finally, the personnel who are responsible for carrying out the actual work that the planned solution calls for usually do not do exactly what they were ordered to do so that the implemented solution may be different from the planned solution. An example application for decision support is presented in Chapter 9.

The way in which the decision support model was designed is as follows. Parameters, prices, suppliers' data, etc. are extracted from a company's database and loaded into the model application. From these data, the model computes values of the performance measures for hypothetical values of the alternatives. The performance measures and alternatives, per se, are not input data to the decision model. In other words, the data elements that are called performance measures and alternatives are generated within the model program and, when the better solution is found by the program, are outputs to the user. Figure 6.3 depicts the modules of the decision making process as considered in the research. There are three modules defined: input module, decision making module, and output module.

The process starts with the user specifying the decision to be analyzed. With the decision to be analyzed known, the following step is to go into the decision making module. The decision to be made is specified as a metadata or intelligent query that allows filtering the data required for the particular decision from all the data available in the company's database, any analytical tools to be used for that particular decision, any alternatives that could be used for that particular decision and any other data elements that could be used.

Once all the data needed is extracted, the next step is to go into the processing module. In this module, a series of models, that could include trial and error analysis, simulation, inventory models, batch size, etc, could be used to find the better solution.

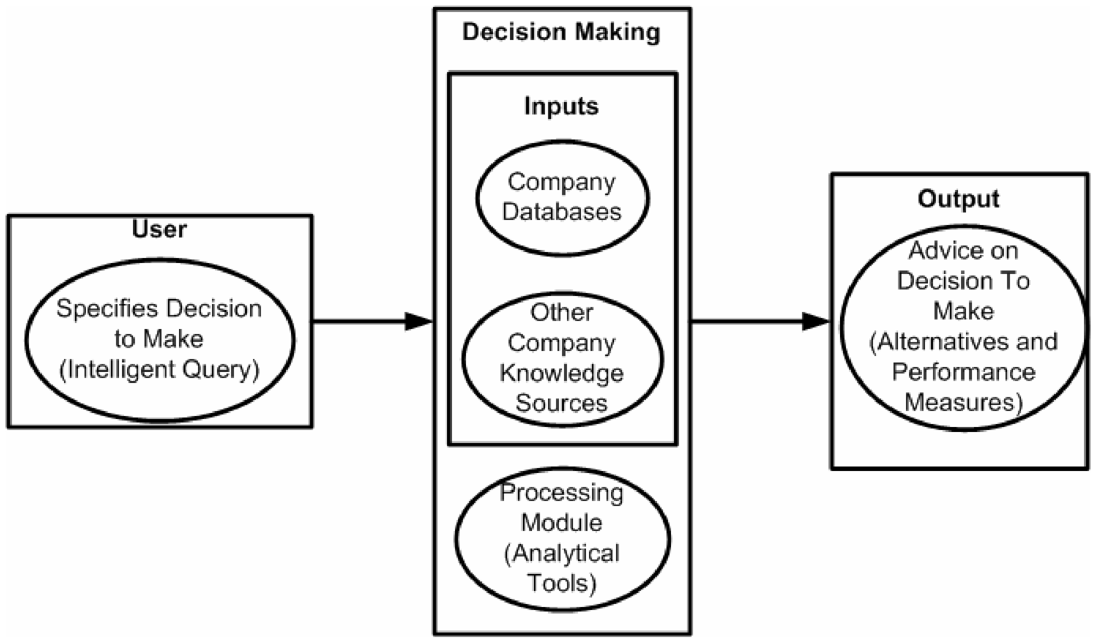

Figure 6.3: Generic Decision Making Process

6.2 Decision Making Processes Studied

Chapter 4 presented the current material management practices in the electrical contracting industry. This representation is based on field interviews with personnel from different electrical contracting companies. Five phases, in which the current management material management practices could be divided, were identified: Bidding Phase, Sourcing Phase, Materials Procurement, Construction Phase, Post-Construction Phase. Decision nodes related to material management in each of the phases were also identified. This research focuses in the material management process during the construction phase. Problematic areas or challenges in the current material management practices were identified. These challenges were described in Chapter 5. Based on the challenges described in Chapter 5, the decision making process was studied to minimize the problems that could be encountered. Six questions that describe the decision making process during the construction phase were identified, this decision making process was analyzed to provide a framework to assist the decision maker. This framework is explained in Chapter 7.

The six questions that were studied by this research are: what type of material to buy and from whom, how much material to buy, when to buy the material, when to deliver the material, where to deliver the material, where to store on site. The decision of what material to buy and from who is important to assure that the correct material is bought. If a different material than the specified is bought, the contractor will incur extra costs to get the correct material. Additional costs due to delays could be incurred. The decision of how much to buy is very important to assure that material quantities needed are available and that there are no material shortages. The decision of when to buy is important to ensure that the material order is placed in time, considering supplier lead time, to minimize delays with deliveries and giving suppliers the required advance notice to deliver the material before it is needed. The decision on when to deliver requires keeping records of the construction schedule and progress of the work in order to have the material available when needed. The decision of where to deliver the material requires space planning and consideration of site limitations, pre-fabrication strategies, and subcontractors to be used. The decision on where to store on site requires space planning and contingencies to avoid damage and to be able to track the material on site.

These six questions were identified from the interviews with electrical contracting companies. Field personnel were inquired about the main considerations when ordering material and what were the main decisions to tackle for this task. Based on their responses and on studying the flowcharts developed, it was concluded that the six questions considered in the study are essential for material management. Therefore, the study was undertaken to model the six decision making process related to these questions and to provide suggestions to decision makers.

This chapter presented an overview of decision modeling and the approach taken to model the decisions considered on the study. A definition of the inputs, represented by the parameters and alternatives, was presented. The performance measures that define the adequacy of the decision made were also introduced. The decisions processes studied were introduced and an explanation of why these decisions were considered was. The following chapter presents the framework for the decision making system. SPARCS, which is a system developed for categorizing parameters, is described in Chapter 8.

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CHAPTER SEVEN: FRAMEWORK FOR A DECISION SUPPORT SYSTEM (DSS) FOR SUPPLY CHAIN MANAGEMENT

As indicated before in this dissertation, materials management problems highly impact general contractors, but are more critical for specialty contractors including electrical contractors. The electrical contractor needs to establish an effective materials management system to minimize problems that might arise if the activities related to materials management are not handled properly. Among these problems, the following are encountered: material shortages, misplacements, loss, and theft, which might result in increases in crew idle times, loss of productivity and delay of activities. Electrical contractors should implement an efficient material management system due to the fact that in most of the cases they are asked to squeeze their bids in order to keep the costs of project under budget. In such a case, failure to effectively manage materials could result in decrease in profit or even a monetary loss. This chapter describes the supply chain management related decisions considered in the study, a graphical description of the processes related to such decisions, which includes the parameters and alternatives for each decision.

7.1 Description of Framework for Decision Models and Description of the Decision Making Process for Supply Chain Management

Chapter 1 introduced the problem statement and the objective of this research work; to use decision-modeling techniques to develop an integrated system of decision support for material procurement for the electrical contractor. Chapter 6 described the decision modeling approach, the factors (or parameters) and alternatives that define the inputs of the decision model. Performance measures are the output of the descriptive decision model. Alternatives represent the different options available for a particular decision. Parameters are uncontrollable factors that influence a decision. The distinguishing characteristics of parameters are that they are not under the control of the decision makers and that they influence the performance measures along with the decision variables. Performance measures are used to measure the effectiveness of the choice of alternatives and parameters used as inputs. This section expands on the description presented in Section 6.2 and presents a description of the framework designed to assist decision makers with decisions related to material management, for the decision considered. In addition, this section will describe the decision making process on the decision nodes, as described in Chapter 5. In the decision making nodes or wherever a decision model is needed, a prescriptive model is used. These decision nodes are illustrated in Figures 7.1 to 7.6 with circles that contain the D.M. inscription inside. The prescriptive model follows the structure illustrated in Figure 6.2.

7.1.1 "What Material to Buy" Decision Node

Figure 7.1 shows the decision process for "what material to buy". This decision node deals with what type of material to buy as well as whom to buy the material from. This will consider requirements of the construction job, progress, schedule, productivity, among other factors. As was presented in Chapter 4, materials used by electrical contractors fall into two main categories: miscellaneous material and major material. The scope of this decision goes beyond deciding whether an item is miscellaneous or major, but, in addition, the alternatives consist of name, (or other identification) of the supplier that is chosen, brand, and the name (or stock-keeping-unit # or sku #) of the item that is purchased. The parameters for this decision node depend on the type of material being considered. Examples of parameters for major material include the brand, size, capacity and cost. One of the most important parameters for major material is the brand (1). Often, the brand of the material to be used in a certain project is specified in the contract documents, therefore the contractor has to buy the material from the specified source. If the brand is not specified in the contract documents, the contractor has two options to obtain material (2). The contractor can use a negotiated process with a manufacturer or a bidding process. As gathered from the interviews, some contractors are in favor of a bidding process because they can get competitive prices by getting manufacturers to bid against each other.

For miscellaneous material the process is similar with the difference that there could be blanket orders or yearly contracts for the type of material being considered (3). If the brand is specified in the contract documents, the contractor verifies whether or not there is a blanket order for that material (4). If there is a blanket order in place, the contractor buys the material from that particular supplier. If there are no blanket orders, the contractor requests bids from different suppliers (5).

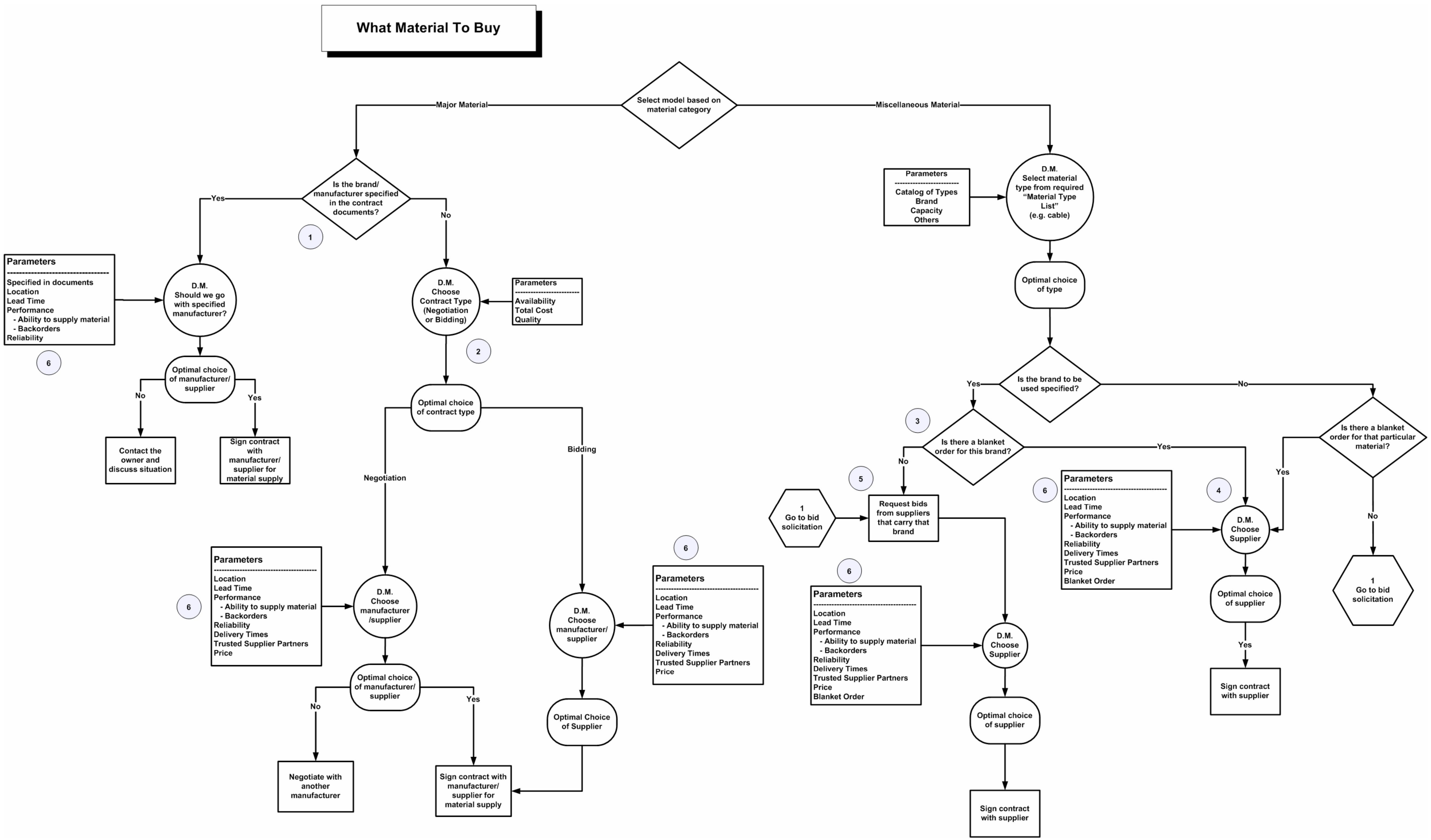

Figure 7.1: Decision Process for the "What Material to Buy" Decision Node

Once the supplying source is identified, the contractor needs to verify that the supplier/manufacturer complies with a series of requirements before signing the contract (6). The first requirement is that the supplier/manufacturer can provide the type of material specified. If the supplier/manufacturer is specified in the contract documents, but the material specified cannot be supplied by this manufacturer, the contractor should talk to the owner about the situation. If the supplier/manufacturer is not specified and the contractor is selecting the supplier/manufacturer, the contractor needs to verify that the selected supplier/manufacturer can supply the material as specified, if not, the contractor needs to negotiate with another supplier/manufacturer.

If the first requirement is met, then the contractor needs to verify the delivery times with the supplying source. Compliance with delivery times is critical to ensure that material is available on site when needed and that there won't be any activity delays or disruptions because of unavailability of materials. Other aspects to consider are the ability of the supplier to provide the quantities needed and that the material will be available on site when it is needed. Availability of material when needed is critical to ensure the progress of the work, to minimize delays in the activities and to minimize idle time of the crews. Absence of materials not only affects the activities that need the material, but also affect other activities. Material needs to be moved and set up to perform work in other activities; crews need to be moved around to perform other activities. Indirect cost will increase with absence of materials. Crews will pretend to be busy even when material is not available, increasing labor costs, which is a big component of a construction project.

7.1.2 "How Much to Buy" Decision Node

The decision of "how much to buy" is very important to assure that material quantities needed are available and that there are no material shortages. In addition, this decision is very important because excess inventory increases storage cost and decreases the available space to store other material. Inventory money is tied into material that is not being currently used. Figure 7.2 illustrates the decision process for "how much material to buy". As gathered form interviews there are three possible alternatives for this decision node: order as estimated in the pre-construction phase, order more than estimated and order less than estimated.

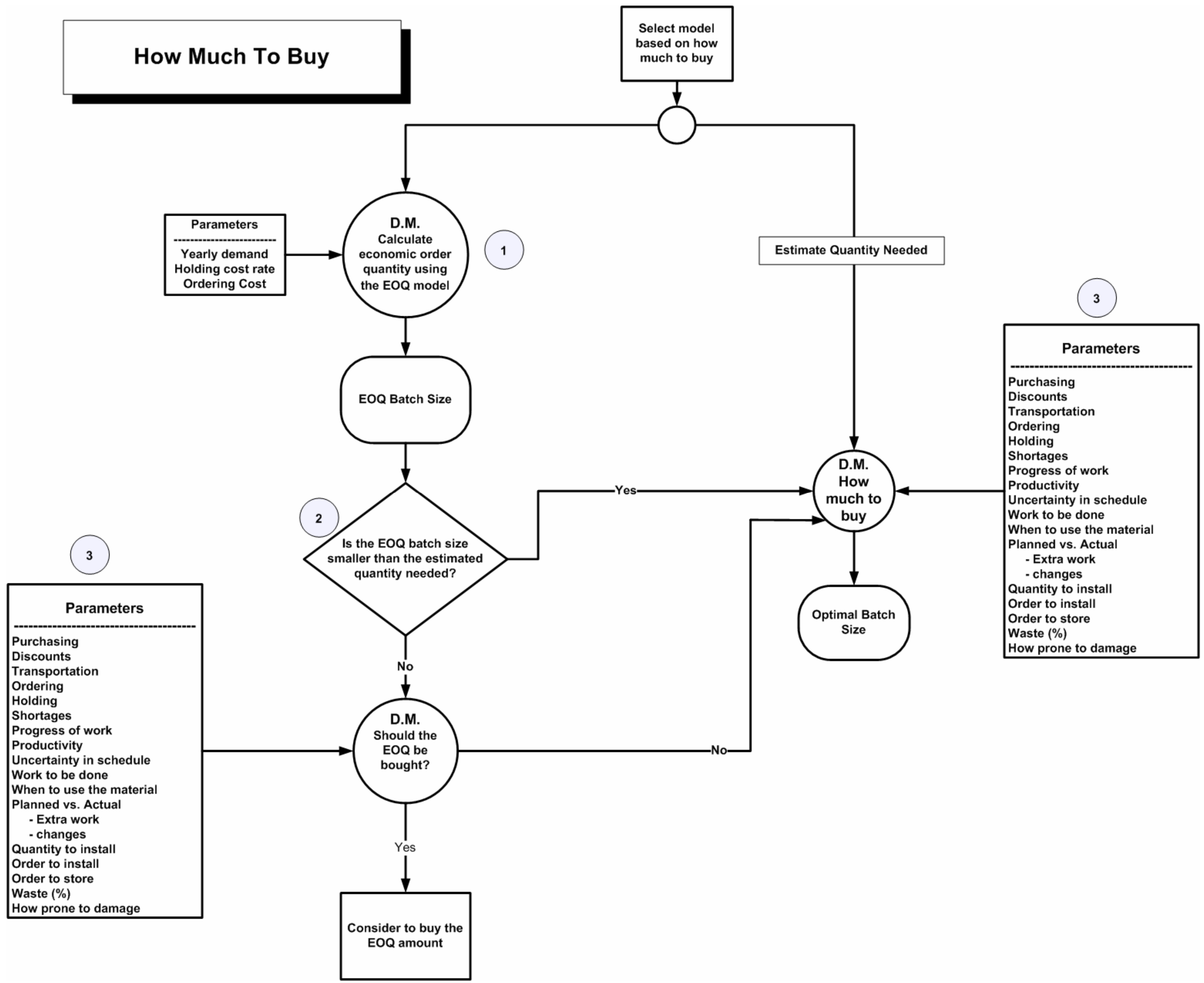

Figure 7.2: “How Much to Buy” Decision Process

An alternative not considered by the contractors was included, the quantity calculated (Q*) from the economic order quantity (EOQ) model (1). This model is further explained in Chapter 9. The quantity calculated with this model is the optimum ordering quantity for a given ordering cost and a given demand. When ordering this quantity, the total costs are minimized. The first step in the analysis of this decision is the calculation of the EOQ. This quantity is then compared to the actual batch size being ordered (2). In order to do this comparison, the descriptive model is used. If the EOQ is less than the actual batch size, then the actual batch size is used to perform the analysis. If the EOQ is greater than the actual batch size, the decision model verifies if the available storage space is sufficient to store the EOQ.

This decision is affected by many parameters, as can be seen in the figure; therefore the contractor has to consider all the parameters that could have an effect in this decision (3). For example, the contractor could verify if the supplier would offer any discounts based on quantities bought. If the supplier offers any discounts, the contractor might consider buying a quantity greater than the actual quantity needed and store the rest of the material for future use. However, this decision is affected by the available storage space available. Similar to this example, there are other situations that require a close analysis before making the decision. The different parameters and the effect that they could have are presented in Figure 7.2. In addition, this figure illustrates the times in which the descriptive model is used in the analysis.

7.1.3 "When to Buy Material" Decision Node

The decision of "when to buy" is important to ensure that material is available when needed. Usually the material requisition process is started by field personnel. The foreman, being in charge of the construction operations, places an order based on the schedule and actual productivity rates. The schedule of the project and installation rates are two critical parameters when considering the time when an order should be placed. In addition, the supplier's lead time plays a key role in the timing when an order is placed. If material is ordered late and the supplier cannot deliver the material prior to the specified lead time, possible delays and work stoppage could be expected.

Figure 7.3 illustrates the decision process for “when to buy material” including the parameters that need to be considered and where the descriptive model is used to assist the decision maker. The decision process is different depending on the type of material needed (1). However, the performance of the supplying source is one of the most important parameters to consider regardless of the material type. The performance of the supplier and relationship between the supplier and the contractor could decide between a successful project or a project full of delays. This performance is given by the lead time required for a particular material to be delivered and by the reliability of the supplier with respect to the ability to supply ordered quantities when needed. If the supplier has a history of being out of stock regularly for certain material and consequently material is often backordered, the contractor needs to consider this aspect when timing the order placements. Major material (2) require a big lead time because this type of material is fabricated specifically for the particular job. This material should be ordered early to avoid delays and possible penalties due to certain owner requirements. An example of an owner’s requirement could be that the owner wants the building to be self powered by the end of the first year of construction. In this case, the transformer needed becomes a critical item because absence of the transformer in the jobsite could increase the possibility of missing the deadline required by the owner, thus possibly incurring fines. Lead times are very small for miscellaneous material. The only problems that could rise from ordering late are the possibility that the supplier is not able to supply the required quantities or that the shipment could arrive a late.

However, miscellaneous materials (3) are common; therefore if a particular supplier cannot supply the total amount required, the rest of the material can be obtained from another supplier. Moreover, as gathered from interviews, the absence of miscellaneous material is not as critical as the absence of major material. If the material will be used for pre-fabrication, the material should be ordered as required by the personnel of the pre-fabrication shop (4). However, the contractor needs to consider if the material will be bought for installation or bought for warehousing (5).

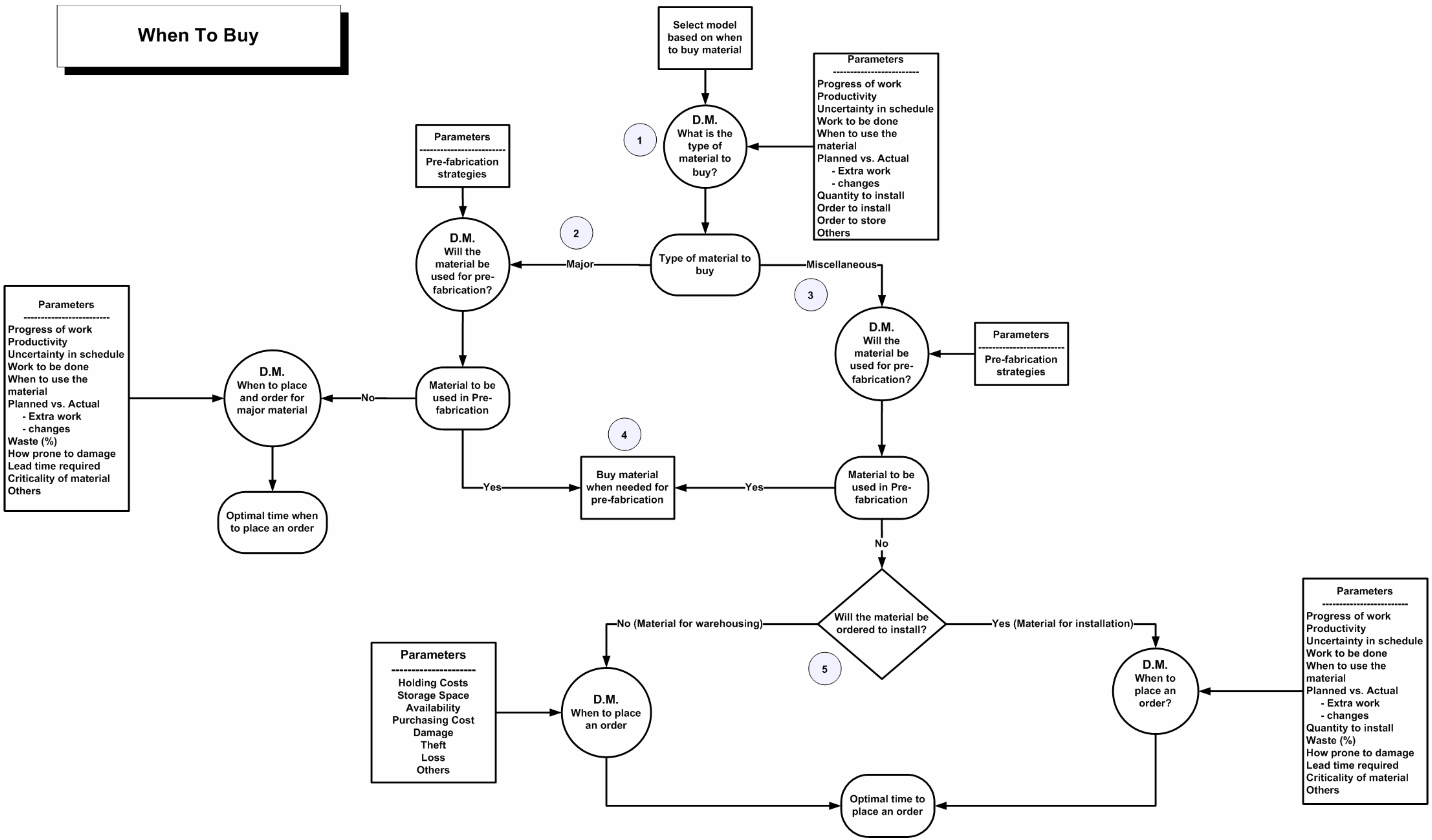

Figure 7.3: "When to Buy Material" Decision Process

7.1.4 *“When to Deliver Material” Decision Node*

Ensuring that material deliveries occur on a timely basis is a very difficult task. Revisions and changes in a project are inevitable. Consequently, the original projected quantities could be different than the actual quantities needed. Changes in design could result in changes in requirements, additions or subtractions for certain material, which could affect the delivery schedule. The contractor has to consider that when changes occur, material could arrive late, the construction sequence could be altered or the fabrication process could be delayed. It is important to consider possible differences between the date that the material was requested to be delivered and the time at which the material will be delivered. Figure 7.4 depicts the decision process for “when to deliver”. As mentioned earlier, the reliability on the supplier is very important for setting delivery schedules.

If the supplier is not a reliable source (1), the contractor would have to buy materials early, which will increase the storage costs. On the contrary, if the supplier is a reliable source (2), the contractor could order materials as they are needed, considering the lead time specified by the supplier. In addition, the contractor needs to consider if the material will be delivered in a single batch or multiple batches. If the material would be delivered in a single batch, the contractor needs to free space and store the material when delivered. If the material will be delivered in multiple batches, the contractor should consider the promised delivery dates for the batches and schedule the material delivery sequence as needed on site. For example, the material to be used in the earlier activities should be delivered first. A very important aspect to consider is the reason for having multiple batches. If the reason for delivering in multiple batches is that the supplier doesn’t have the quantities needed, the contractor needs to be aware about possible backorders which could delay the work.

On the other hand, if the multiple batches are due to the supplier’s inability to deliver the entire material order in a single shipment, the contractor should ask the supplier to deliver the material as soon as more transportation equipment becomes available. Figure 7.4 illustrates how these factors (3) are considered in the decision and where the descriptive model is used in the analysis.

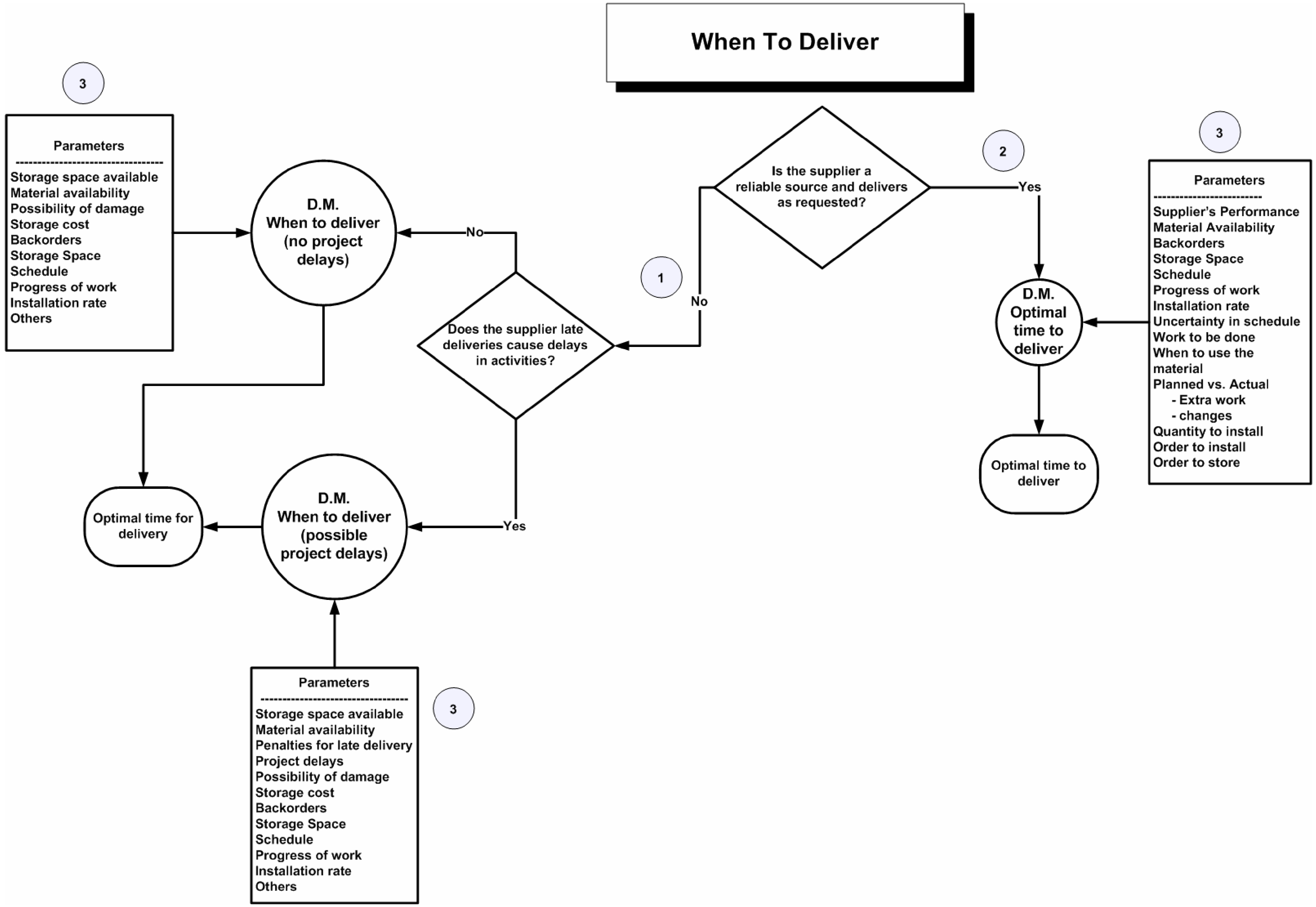

Figure 7.4: “When to Deliver” Decision Process

7.1.5 “Where to Deliver Material” Decision Node

The decision of “where to deliver material” requires space planning and consideration of site limitations, pre-fabrication strategies, and subcontractors to be used. Figure 7.5 shows the “where to deliver” decision process. The possible alternatives for delivery are jobsite, warehouse/pre-fabrication shop and subcontractor. Material is generally requested for delivery to the job site. In some instances delivering material directly to the jobsite may not be feasible due to storage or access limitations. In this case, the material is delivered to other locations such as the contractor’s warehouse or another subcontractor storage area. The parameters that need to be considered are the criticality of the item, whether the material will be used for pre-fabrication (1) or not, whether the material was ordered to install or ordered to store, the available space for storage in all possible locations.

Material is delivered to the warehouse if it is a critical item that needed to ordered early and will not be installed immediately or when the item will be used for pre-fabrication. Materials are delivered to a subcontractor’s yard when a subcontractor is needed for installation (2). Most of the contractors interviewed prefer to deliver the materials to the jobsite directly and store in sea cans. The descriptive model is used to analyze all these factors (3) and how they influence the decision to be made.

7.1.6 “Where to Store On Site” Decision Node

The decision for “where to store material on site” is important to minimize theft, loss or damage. Ideally, the contractor would like to store the material to be used the next day on the work area (1). The ability to store material on the floor of the building depends on any restrictions (2) imposed by the general contractor with respect to on-floor storage, number of trades working at the same time and possibility of damage. If there are multiple trades working at the same time, the contractor might have to move the material around to free space for the other trades, a factor that can increase the indirect costs due to re-handling.

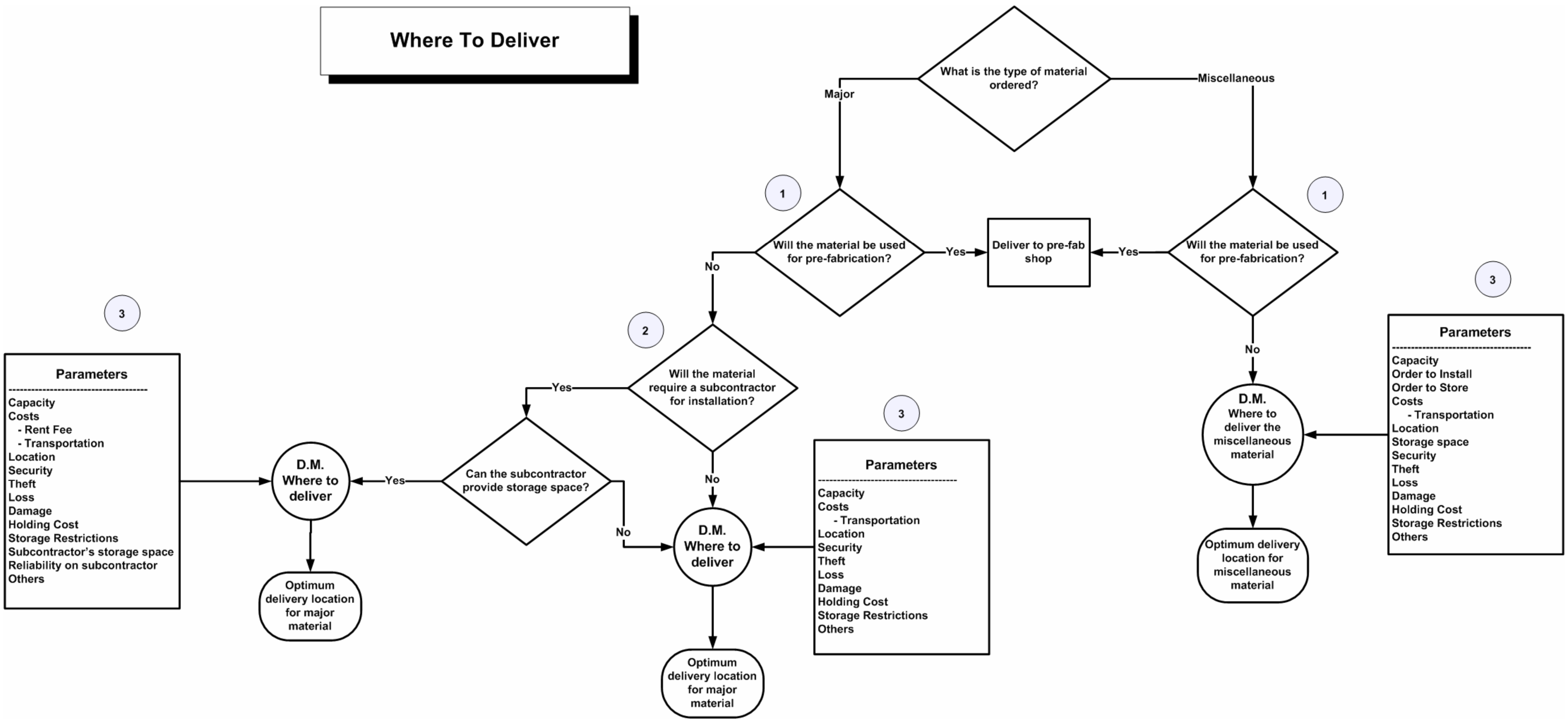

Figure 7.5: “Where to Deliver” Decision Process

Another alternative (3) for the contractor is to store material in the laydown areas next to the building. There is a concern related to the possibility of material being damaged by equipment, people or the weather. In addition, many contractors stated that in many projects the laydown areas around the buildings are limited, thus storing material in such areas is limited and often not allowed.

The alternative that is commonly used by most contractors is to store the material in sea cans and move it to the building as needed for installation. Figure 7.6 illustrates the decision process for "where to store on site". The process illustrated in the figure considers all the possible alternatives for on site material storage and the factors (4) that affect this decision.

7.2 Summary

This chapter presented a description of the decision making process for the electrical contracting industry. Figures 7.1-7.6 presented graphical descriptions of the decision making process for material management. The next chapter will describe a proposed system to classify parameters needed in the decision making process. In addition, the chapter will describe a framework for a computer based decision support tool for material supply chain for the electrical contracting industry.

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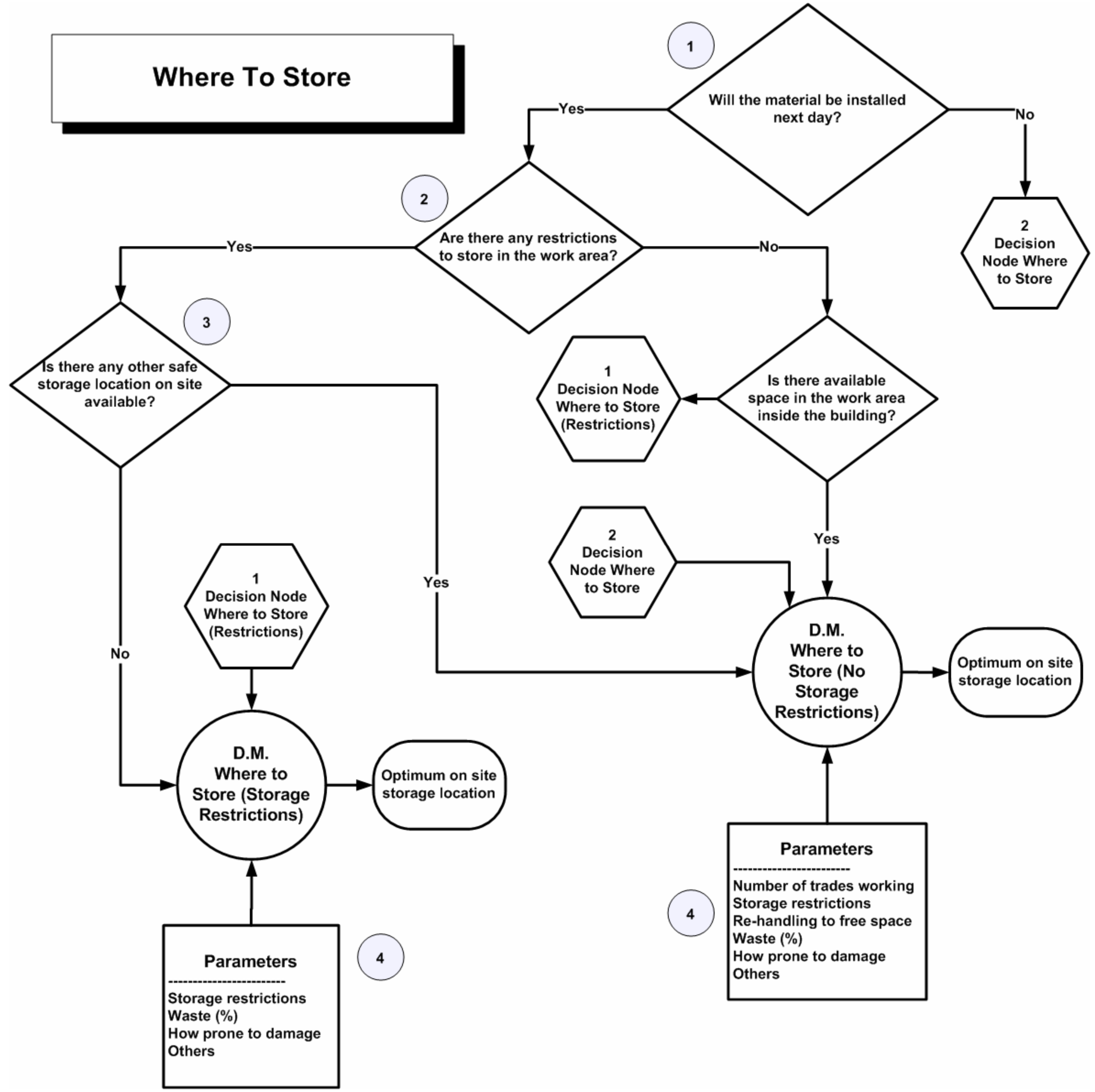

Figure 7.6: "Where to Store" on Site Decision Process

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CHAPTER EIGHT: SPARCS - SUPPLY-CHAIN PARAMETERS CLASSIFICATION SYSTEM

The performance of the material-procurement decisions is heavily dependent on the combination of the different alternatives associated with every phase of the materials management process and the factors or parameters that influence the selection among the different alternatives for each particular decision. These parameters need to be extracted on a regular basis as decisions related to material management are ever present in a construction project. The identification of parameters is a task that requires more attention, since parameters related to different areas, such as schedule, suppliers, among others, need to be considered. These parameters can be acquired from different sources such as historical databases, the internet, and suppliers, among others. The identification and extraction process for the parameters could be tedious and time consuming because the decision maker could be extracting the information from unstructured records that contain vast amounts of data. In addition, important parameters that relate to different categories such as schedule, storage, cost, among others, need to be extracted and sorted. This chapter describes a framework/structured approach developed for parameter classification.

8.1 SPARCS

Currently, there is no structured model to categorize the parameters that need to be considered on the supply chain decision making process for the electrical contractor. The electrical contracting industry needs a structured database design that can allow decision makers to review and categorize these parameters. This categorization could facilitate the storage and classification of the parameter information for future extraction and use. As part of this research, a structured approach was defined for parameter classification only. For a more complete system design and model specification, a similar approach needs to be developed for alternatives and performance measures. This development could be the basis for future research.

Based on the information gathered through interviews with the electrical contracting industry personnel and through extensive literature reviews, a system for classifying parameters for material supply chain was developed. **SPARCS**, an acronym for **S**upply-chain **PAR**ameter **C**lassification **S**ystem, is a classification structure for supply chain parameters. The development of SPARCS begins with a hierarchical framework. This approach conforms to generally accepted methods of structured systems development. SPARCS will be the basis for future development of a relational database to share and organize parameter information. In addition, the development of SPARCS could help contractors in understanding how some of the particular database applications work. For example, SPARCS could give the contractor an idea of how an Enterprise resource Planning (ERP) system was set up and the data that could be part of that system. In future research efforts, this hierarchical framework could be developed into a relational database design.

For the development of SPARCS, the decision support systems (DSS) used in the materials management decision process are described as independent systems for each decision to be made. This means that each DSS extracts the information needed from a data source that contains the specific data required, in our case the SPARCS categories, to analyze that particular decision as described in Figure 8.1. The figure illustrates three of the six decisions that are considered in the study. The ideal situation would be to have one database that contains all the data required to perform the analysis of the six decisions considered in this study. The development of such database system is out of the scope of this research; however the development of SPARCS covers some of the initial steps required for the development of such database.

Figure 8.2 depicts the activities required for database development. There are seven activities identified in the figure (McFadden et *al*, 1999): project identification and selection, project initiation and planning, analysis, logical design, physical design, implementation and maintenance. In the project identification and selection activity, the range and general contents of the organizational database are set. In the project initiation and planning activity, the scope of the data involved in the development project is outlined. In the analysis activity, a detailed data model is produced and all the information needed for the information system is identified. In the logical design activity, the conceptual data is transformed into relations by using entity relationship diagrams (ERDs).

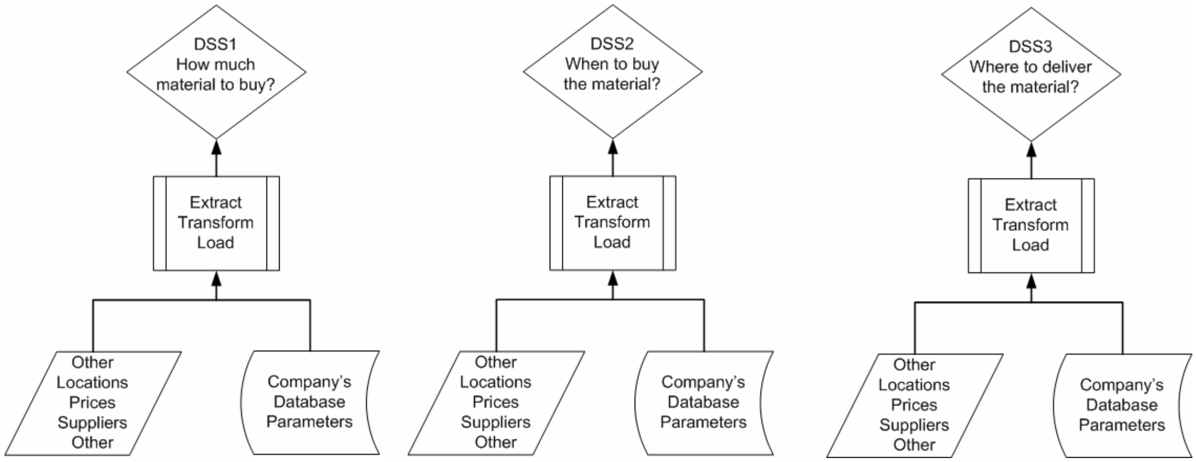

Figure 8.1: Description of Structure of the Decision Support Systems

The physical design activity involves disk allocations and physical allocations of the databases. The implementation activity involves testing the database with programs used by the company. The maintenance activity involves tuning the database to keep it up to date with information generated and fixing problems with the database.

Figure 8.2 also depicts the activities that SPARCS addresses in the database development activities. SPARCS covers the first two activities and a very small part of the third activity. The information requirements for the application to be developed are defined, the contents of the overall database of parameters are described within SPARCS, the overall data needs for the material supply chain process are defined and detailed models that identify the data needed for the decision support system are identified.

There are several points that need to be addressed with respect to the development of SPARCS and the model:

1. Decision models are never perfect and are always being updated and enhanced. The hierarchical definition of SPARCS allows updating the parameter classification and structure of the system easily.
2. The data requirements of a decision usually change when the decision model is changed. SPARCS allows extracting data to be used as inputs in accordance with the decision to be analyzed.

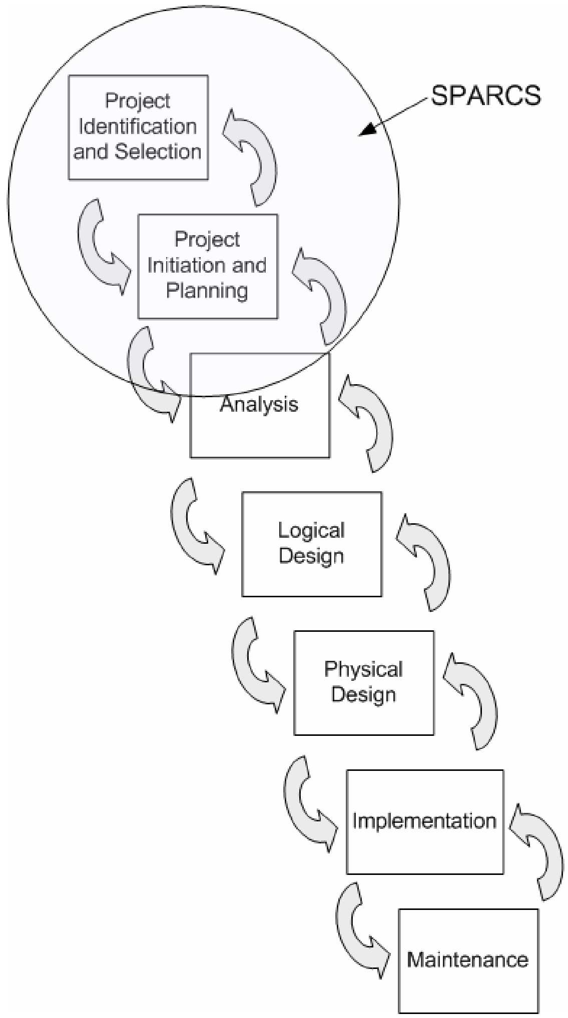

Figure 8.2: Database Development Activities (Source: McFadden et *al*, 1999)

3) Database design and data collection take a long time to complete. The database development process was presented in Figure 8.2. As mentioned, the described development of SPARCS only covers two and a half stages of the process of database development.

4) The facts mentioned in points 1 to 3 imply that, in order to have the data available whenever a decision model is changed, the database must be built in anticipation of future decision-model developments. In other words, the database must be defined comprehensively with all possible decision models in mind. This is the approach taken in designing and investing in ERP systems and data warehouses.

8.2 Development of SPARCS

SPARCS allows classifying and organizing supply chain related parameter information into various categories. This classification can be used as the structure to create the database that will store the parameter information. Parameters needed by the decision maker at any instant can then be extracted from the respective category in the database under the SPARCS classification.

The first step in the development of the system was to gather information from interviews with companies and literature review. Once the information was gathered, the decision nodes for material supply chain were identified, and the data needed as inputs (i.e. parameters) and the data generated as outputs (optimal decision variables and performance measures) for all the decision nodes were also identified. Once the data were identified, categories under which the parameters could be classified were defined for each decision. Examples of the categories include cost, schedule and storage. Categories could also contain sub-categories. For example, the cost category can be subdivided into direct and indirect cost. The parameters are then classified into the respective category and subcategory, if applicable. Each category is comprised of parameters that can directly influence that category. For example, some parameters that are included in the storage category are capacity, cost, etc.

It could be argued that ERP databases that are currently available were designed to address decision support in all aspects of a business enterprise. However, the development of SPARCS presents the following research contributions:

1) It defines the database that would be extracted from ERP databases or other company data sources in order to support specific decisions.
2) It defines data that may have to be extracted from different corporate entities and different corporate databases (general contractor, sub contractor, suppliers, and owner).
3) It assists in the development of small-scale decision support that a sub-contractor may utilize in the absence of an ERP system.

8.2.1 Data Definition for SPARCS

A data dictionary is a collection of descriptions of the data items in a data model to facilitate the understanding of such data to users who need to refer to them. In its simplest form, the data dictionary is only a collection of data element definitions (Mattila, 2001) or a document prepared by the developer to describe all items in a database. Figure 8.3 depicts the general structure of SPARCS. In a hierarchical diagram definition, this type of diagram could be referred to as a parent-child description. The entry point, or parent, is the decision to make. The classification of the parameters in SPARCS depends on this decision. Once the decision to be made is known, the next step is to identify the Category in which the parameter fits. A Category is the main class used to classify a parameter. Categories were selected based on the main information components that can be found in a typical construction project. Categories could contain Sub-categories that are used to further divide the Categories into components that could facilitate the classification of the parameters. For example, the Cost category can be further divided into two categories: Direct cost and indirect cost. The use of sub-categories allows classifying parameters more specifically based on the cause that the parameters could have on the overall decision system. For example, a contractor could easily identify that material not being available when needed creates an indirect cost associated to losses in productivity.

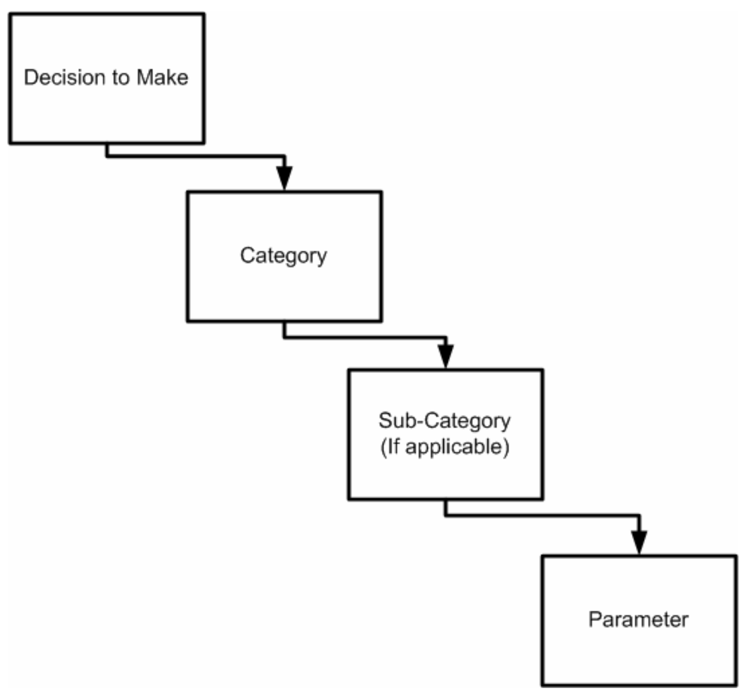

Figure 8.3: General Structure of the SPARCS System

Figure 8.4 depicts detailed description of the SPARCS hierarchy, including information that is related to all the decisions that were considered in this research.

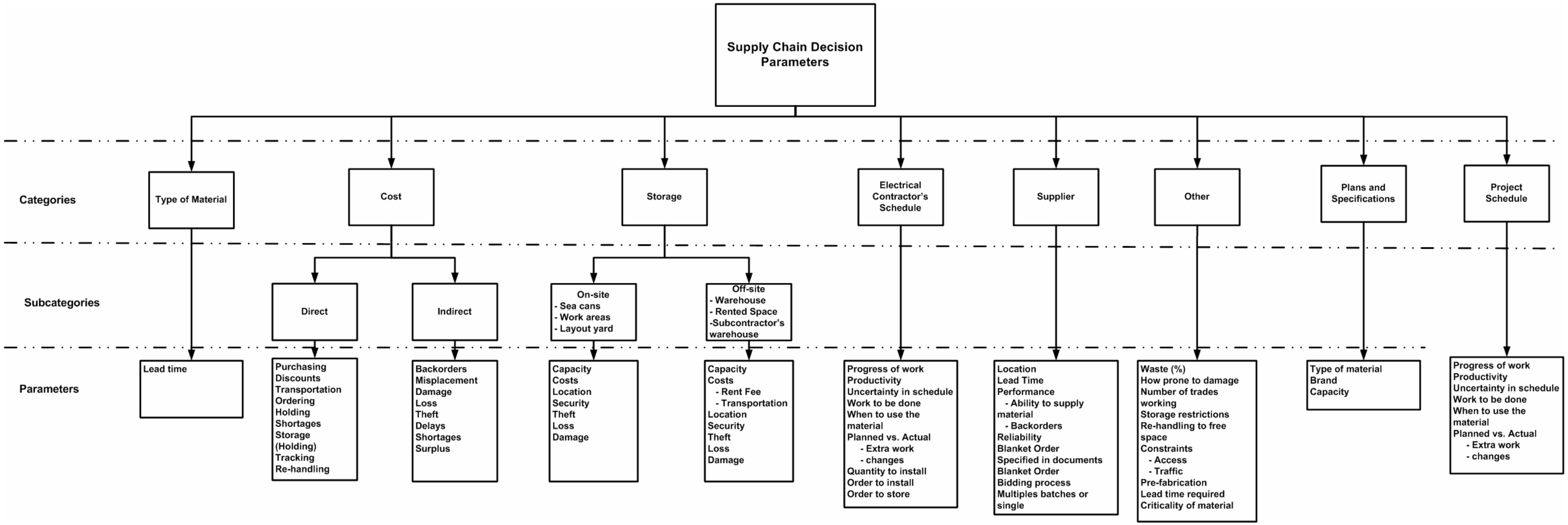

Figure 8.4: The SPARCS Hierarchy

The main categories identified are: Type of Material, Cost, Storage, Schedule, Supplier, Other and Plans and Specifications. Subcategories are used to further divide the Cost and Storage categories into direct or indirect cost and on-site or off-site storage. The parameters are then classified into the appropriate category and subcategory. The parameters needed for every decision to be analyzed are filtered from the SPARCS hierarchy. Figures that describe the parameters for each decision are presented further in this chapter.

Table 8.1 presents the dictionary definition for the categories and sub-categories used in the SPARCS hierarchy.

Categories	Definition	Components
Cost	Total amount of money paid to have material available on site	Direct Cost, Indirect Cost
Type of Material	Type of material to be bought	Major material or commodities
Storage	Location and/or space where the material will be placed until installation	On-site, Off-site
Schedule	Planned calendar of the work to be performed	Progress of work Productivity Uncertainty in schedule Work to be done When to use the material Planned vs. Actual - Extra work - changes Quantity to install Order to install Order to store
Supplier	The source that will supply the material needed	Location Lead Time Performance - Ability to supply material - Backorders Reliability Blanket Order Specified in documents Blanket Order Bidding process Multiples batches or single
Plans and	Contract documents of the work	Type of material

Specifications	to be performed given by the owner or his representative to the contractor	Brand Capacity
Other	Use to classify the parameters that don't fit in any of the categories presented above	Waste (%) How prone to damage Number of trades working Storage restrictions Re-handling to free space Constraints - Access - Traffic Pre-fabrication Lead time required Criticality of material
Sub-Categories	Definition	Components
Direct Cost	Cost of purchasing and having the material available on site.	Materials selling cost, procurement costs (cost of placing processing and paying of material, physical distribution, distributor's cost, and transportation costs), and site-handling costs (cost of receiving, storage, issuing, and disposal)
Indirect Cost	Cost due to unavailability of materials, misplacements, multiple orderings	Loss in labor productivity, misidentification, duplicate orders, delays, etc.
On-site Storage	Space available on the jobsite to store material	"Sea Cans" or trailers, laydown areas, work areas
Off-site Storage	Space own or rented in a remote location for storage purposes	Warehouse, pre-fabrication shop, sub-contractor's yard

Table 8.1: Data Definition for the Categories and Sub-categories

Similar to Table 8.1, Table 8.2 presents examples of parameter definitions, which represent the child in a parent-child relationship.

Parameter	Definition	Category
Lead Time	Time between the placement of an order and delivery to the construction site	Type of Material
Purchasing	The price of a particular material	Cost

Ordering	The cost of placing an order of material	Cost
Discounts	Any reductions in cost due to amounts bought or any other arrangement	Cost
Transportation	Cost of transporting the material from the supplier's location to the jobsite	Cost
Shortages	Cost associated with having less material available than required on the jobsite	Cost
Storage (Holding)	Cost of storing material on the jobsite for future use	Cost
Tracking	Cost of tracking material to avoid theft or losses	Cost
Re-handling	Cost of moving material around to free space or to bring it to the work area	Cost
Surpluses	Cost associated with having more material available than required on the jobsite	Cost
Backorders	Cost associated with material not available and being ordered by the supplier	Cost
Misplacement	Cost associated material misplaced and not available when needed	Cost
Damage	Cost associated with material being damaged by the weather, equipment, workers or other material	Cost
Loss	Cost of associated with material being lost	Cost
Theft	Cost of associated with material being stolen	Cost
Delays	Cost of associated with material not delivered when promised by the supplier	Cost
Capacity	The amount of material that can be stored on a particular location	Storage
Rent Fee	Cost of renting additional space for material storage	Storage
Location	Physical location of the storage facility	Storage
Security	How secure is the storage location with respects to theft of material	Storage
Progress of work	Work development and progression	Schedule
Productivity	Installation rate of material	Schedule

Uncertainty in schedule	The accuracy and possible changes in schedule due to uncertain events	Schedule
Work to be done	The work to be performed on a particular work day	Schedule
When to use material	Expected date for material installation based on schedule or actual work progress	Schedule
Extra work	Any additional work requested by the owner and not indicated in the contract documents	Schedule
Changes	Changes in the original work to be performed	Schedule
Quantity to install	Material quantities to be install based on the type of work to be performed	Schedule
Order to install	Material that is ordered for immediate installation	Schedule
Order to store	Refers to material being ordered to be stored for future use	Schedule
Location	Refers to physical location of the supplier	Supplier
Performance	Refers to the ability to supply material and in addition backorders expected	Supplier
Reliability	How trusted is the supplier with respects to delivery and availability	Supplier
Blanket Order	Contract with supplier for usually a year to supply commodities specified	Supplier
Specified in contract	Any restrictions on the contract documents to use certain supplier	Supplier
Bidding Process	Selection of the supplier based on a bidding process as opposed to a negotiated agreement	Supplier
Multiple batches or single	The number of deliveries for a particular order	Supplier
Waste	Amount of material expected to be wasted	Other
How prone to damage	How easy a material can be damaged due to weather, equipment or people	Other
Number of trades working	How many contractors are working at the same time in the same work area	Other
Storage restrictions	Any restrictions with respect to storage areas and spaces	Other
Re-handling to free space	Material that has to be moved around to free space to work	Other
Constraints	Any restrictions for material delivery	Other

Access	Constraints associated with available access to the jobsite	Other
Traffic	Constraints associated with traffic for material delivery to the jobsite	Other
Pre-fabrication	Different material components being assembled into a single unit before installation	Other
Criticality	The impact in schedule or a milestone set by the owner that the absence of material could cause	Other
Brand	Manufacturer of the material	Plans and Specifications
Capacity	Operational specifications of a particular material	Plans and Specifications

Table 8.2: Example Data Definition for Parameters

This section described the development and data description for SPARCS. The following sections will describe SPARCS for the decisions considered in the study.

8.3 SPARCS for the 'How Much to Buy' Decision

Figure 8.5 shows the SPARCS model for the how much to buy decision. The main categories that apply to this decision are cost, storage, schedule, supplier and other.

The storage category comprises two options: on-site storage or off-site storage. The options for on-site storage are to store in "sea cans" or trucks, store in work areas or store in the laydown areas. The parameters associated with the on-site storage are storage capacity, storage costs, storage location, security, theft, loss and damage. The alternatives associated with off-site storage are warehouse, rented space and subcontractor's yard. The parameters associated with the off-site storage are storage capacity, storage costs (rent and transportation), storage location, security, theft, loss and damage. Another category associated with this decision is the schedule. Parameters under this category include progress of work, productivity, uncertainty in schedule, work to be done, when to use the material, planned vs. actual (i.e. extra work, changes), quantity to install, order to install or order to store. The other categories associated with this decision are supplier and other.

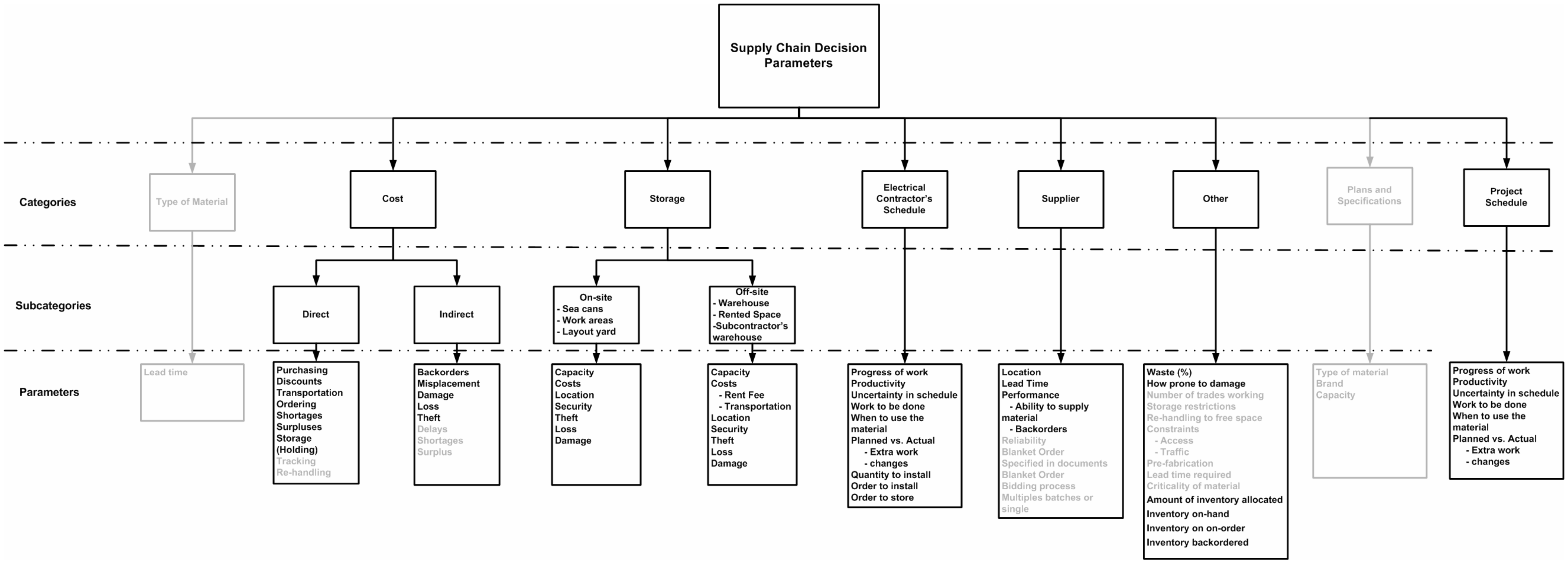

Figure 8.5: SPARCS Model for the Decision on How Much to Buy

The total cost of materials includes direct costs and indirect costs. These are two subcategories under the Cost category. Direct costs are comprised by materials selling cost distribution, distributor's cost, transportation costs, and disposal. Indirect costs may include costs due to misplacement, damage, loss, cost of placing processing and paying of material, cost of receiving, storage, issuing, among others. The cost category can be seen in Figure 8.5.

8.4 SPARCS for the 'What Material to Buy' Decision

The type of material to use in a construction project is specified in the specifications and in the drawings. Therefore, it is expected that plans and specifications comprise one category for parameters for this decision. Figure 8.6 depicts the SPARCS diagram for the type of material to buy decision. For this decision, the main considerations are the brand of the material to buy and from which supplier to buy it. The main categories for this decision are Cost, Plans and specifications, Schedule and Supplier.

The total cost is comprised by direct and indirect cost. Direct costs include the purchasing cost, discounts, and ordering. Indirect costs include cost associate with backorders. The supplier category is important because the brand of the material to be used in a particular project could be specified in the contract documents. Some materials are only carried by specified suppliers; therefore this material needs to be acquired from those suppliers. If the material brand is not specified, the contractor can select the sourcing source either through bidding, negotiated contract or a blanket order.

8.5 SPARCS for the 'Where to Deliver' Decision

The decision of where to deliver requires space planning and an understanding of the work schedule and actual productivity at the job site. It is critical to have the material available in the jobsite when needed to avoid delays. Usually material is delivered to the jobsite, but in other instances it is delivered to other locations such as a warehouse/pre-fabrication shop, a subcontractor’s yard for storage and subsequent installation. The decision is based on the different parameters that could restrict the decision.

The main categories that apply to this decision are: cost, schedule, storage and supplier. The contractor needs to consider the direct storage cost of each alternative before making a decision on where to send the material for storage. Moreover, the contractor needs to consider other indirect costs associated with each storage alternative such as damage while the material is stored, loss or theft.

Any of these factors can greatly affect the availability of material when needed, even more if the material being stored is a critical material. Absence of a critical material when needed affects the construction schedule greatly. The production and availability of a critical material requires long lead times, therefore it is very important to consider the storage location for such material.

The space available at each storage alternative is critical when making this decision. If there is available space and the material will be used in the near future, the contractor should consider storing the material at the jobsite. However, as seen from the SPARCS diagram, this decision is based on space availability, storage restrictions, storage fees, possibility of damages and loss.

The performance of the supplier plays an important role when making this decision. As seen in the SPARCS diagram, the location, lead time and performance are essential parameters to consider when considering this decision. For example, if the supplier doesn’t meet delivery dates, the contractor will have to buy material early and store it in different locations to ensure availability when needed. This will increase indirect costs to the contractor related to re-handling, storage and risk associated with damage. Figure 8.7 depicts the SPARCS system for the where to deliver decision.

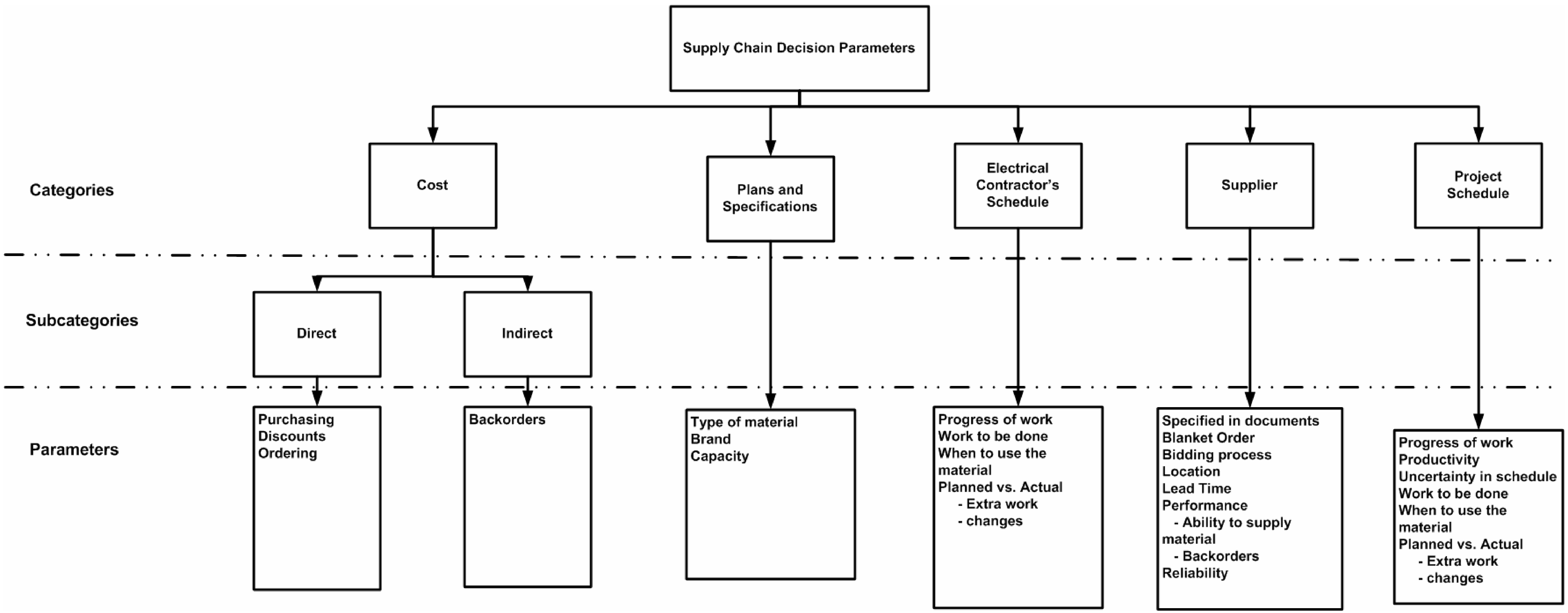

Figure 8.6: SPARCS for What Material to Buy Decision

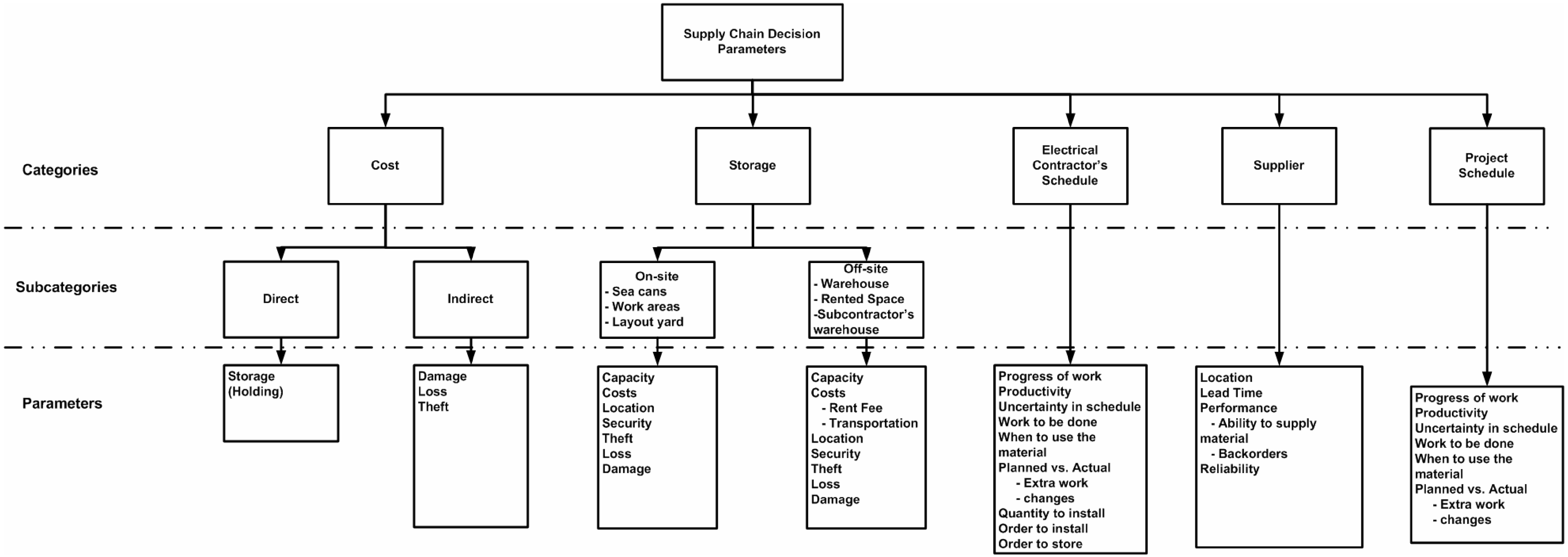

Figure 8.7: SPARCS for the Where to Deliver Decision

8.6 SPARCS for the 'Where to Store on Site' Decision

Often the available space for storage in the laydown areas is limited. The numbers of trades working at the same time influence the space available for storage in the laydown areas as well as the available space for storage in the building. In addition, the progress of the work and the number of trades working in the same area influence the number of times that material stored on the floor of the building needs to be moved around to free space for the other trades. These are some of the parameters that affect the decision on where to store the material on the construction site.

The main categories for this decision are cost, schedule, storage and other. Under the other category, the possibility of material being damaged is encountered. The contractor needs to consider the possibility of material being damage when selecting a storage location. Quality is a very important aspect to achieve in a construction project. If material is damaged while stored and the contractor decides to store the damaged material not only re-work would have to be done, but, in addition, the contractor might not get future jobs due do this behavior. Therefore, the contractor should avoid damages and the cost associated with reordering material.

If the material will be used the next day or the day after, based on productivity and progress of the work, the contractor should consider storing the material close to the building, if there is no space available on the floor. However, storage restrictions, loss, security, damage, among other factors need to be considered.

All the parameters, as described by SPARCS that could have an effect on this decision need to be considered to avoid damages, loss, theft, consequently minimizing the possibility of absence of materials when needed. Figure 8.8 shows the SPARCS diagram for this decision.

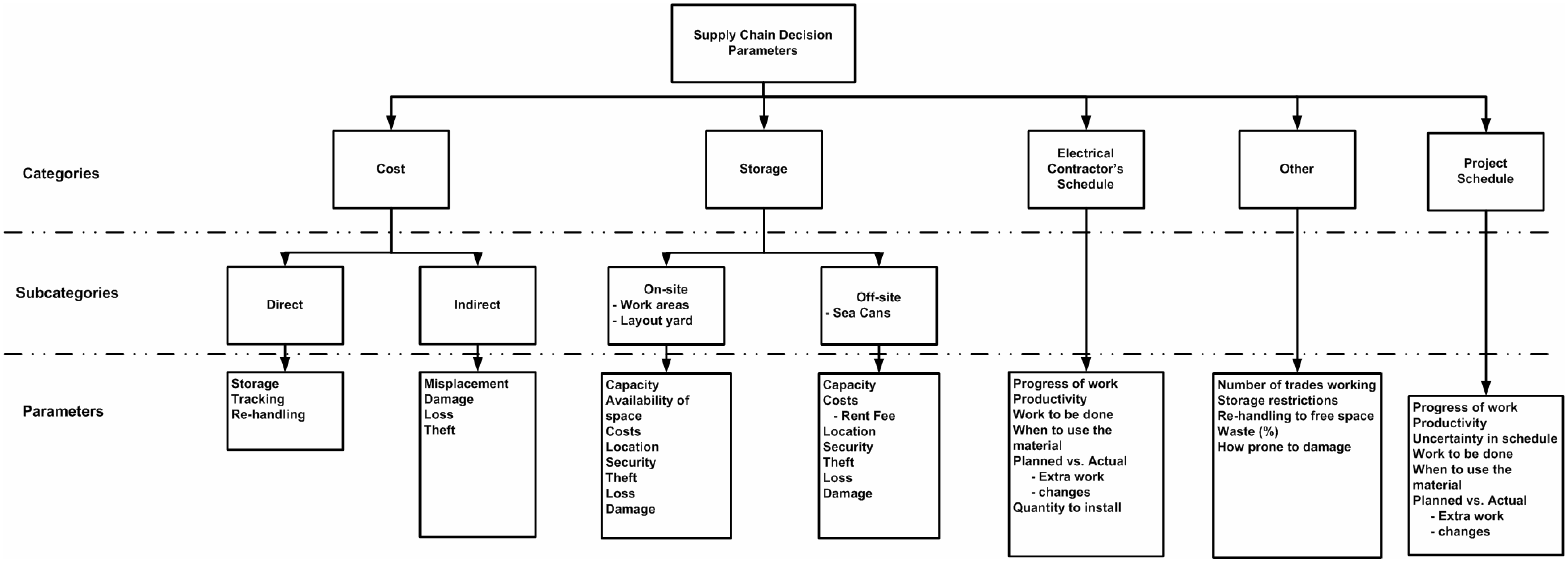

Figure 8.8: SPARCS for the Where to Store on Site Decision

8.7 SPARCS for the 'When to Deliver' Decision

Availability of material is the most critical aspect to consider. The absence of materials when needed can increase the time required to finish an activity. In addition, the indirect cost associated with absence of materials is high because the contractor still has to pay salary for the crews. The decision of when to deliver requires space planning.

The main categories for this decision are cost, storage, supplier, schedule and other. The performance of the supplier plays a critical role in this decision. If the supplier is a reliable source, the contractor could request deliveries the day before the material will be used. Otherwise, the contractor will have to order the material in advance and store it at the jobsite.

The contractor needs to consider any constraints that could affect the delivery of the material. Access constraints to the jobsite could affect the type of equipment that could be used for delivery and instead of a single delivery the material could be delivered in multiple batches. In addition, traffic could play a role in delivery. If heavy traffic is expected in the area where the construction is taking place, the contractor should consider having the material delivered at times when the traffic is not in the peak. Deliveries in such environments could be restricted in the contract documents in order to minimize impacts to traffic.

As seen in the Figure 8.9, the available storage space is essential when scheduling deliveries. The progress of the work and usage of the material have a direct effect on the storage space available. Therefore, the contractor needs to verify the schedule, progress of the work and installation rate to ensure that the material is delivered when needed. If the orders are placed on estimated productivity, but if the work is progressing at a faster rate than estimated, the contractor will be in problems because material will not be available when needed. Therefore, the contractor needs to consider all the parameters described by SPARCS for this decision. Figure 8.9 shows the SPARCS hierarchy for the when to deliver decision.

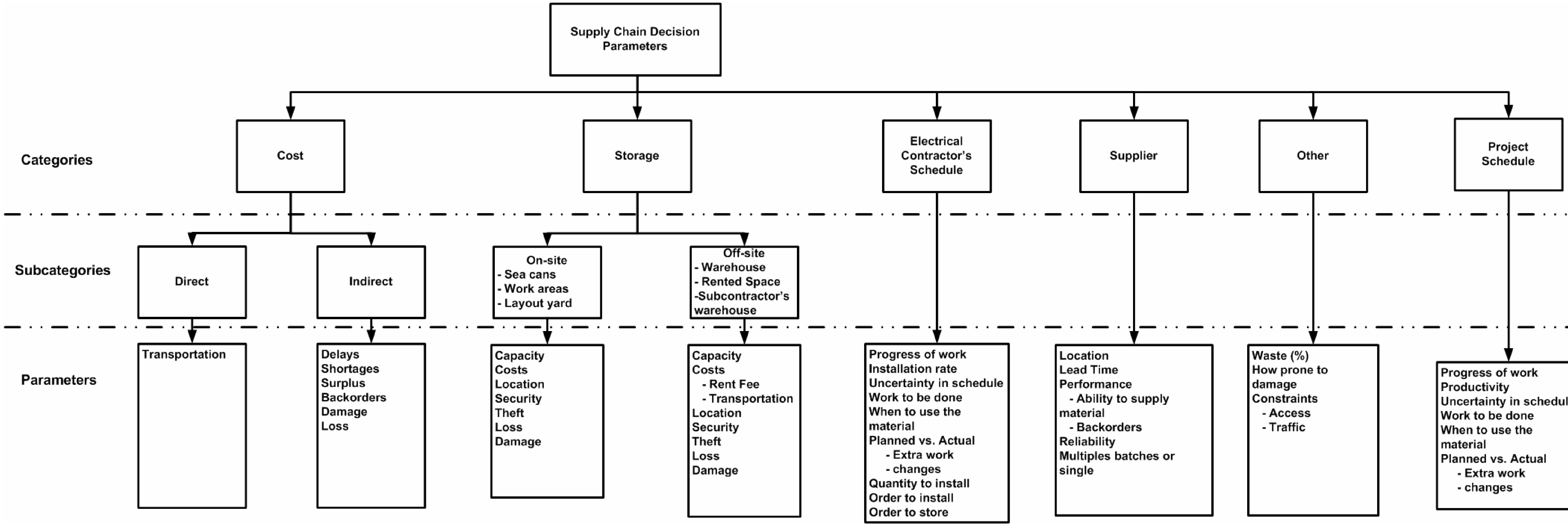

Figure 8.9: SPARCS for the When to Deliver Decision

8.8 SPARCS for the ‘When to Buy’ Decision

The timing of placing orders is essential to ensure that the material will be delivered when needed. Usually orders are placed based on the lead time required by the supplier. This lead time is the time required by the supplier to deliver an order from the time that it is placed. For miscellaneous material the lead time is relatively small. In the contrary, for major material the lead time is usually weeks. The contractor needs to consider the type of material to buy in order to establish the times at which order will be placed. This is only one of the parameters to consider when timing the order placing.

The main categories for this decision are type of material, cost, storage, schedule, supplier and other. As discussed earlier, the lead time for the material depends on the type of material to be bought.

The contractor should consider to buy material early if some discounts could be achieved by ordering such material early or if increases in material cost are expected in the near future. An example of material that could increase in cost is cable. Copper prices fluctuate and this affects the price of cable. However, the contractor should consider the storage cost of having this material early against the savings that could be achieved.

The when to buy decision is affected by the performance of the supplier. As was discussed earlier, if the supplier is a reliable source, the contractor could schedule deliveries the day before the material will be used. In the majority of the cases this is not possible and the contractor should schedule the deliveries within reasonable time (i.e. a couple of days) before usage.

Another parameter that affects this decision is the fact that the material could be bought for installation or for storage. If a shortage of certain material is expected in the near future, the contractor could buy the material and store it until use to ensure availability of the material when needed. The contractor needs to consider all the parameters that could have an effect on this decision, especially those associated with availability on the jobsite when needed. Figure 8.10 depicts the SPARCS system for this decision.

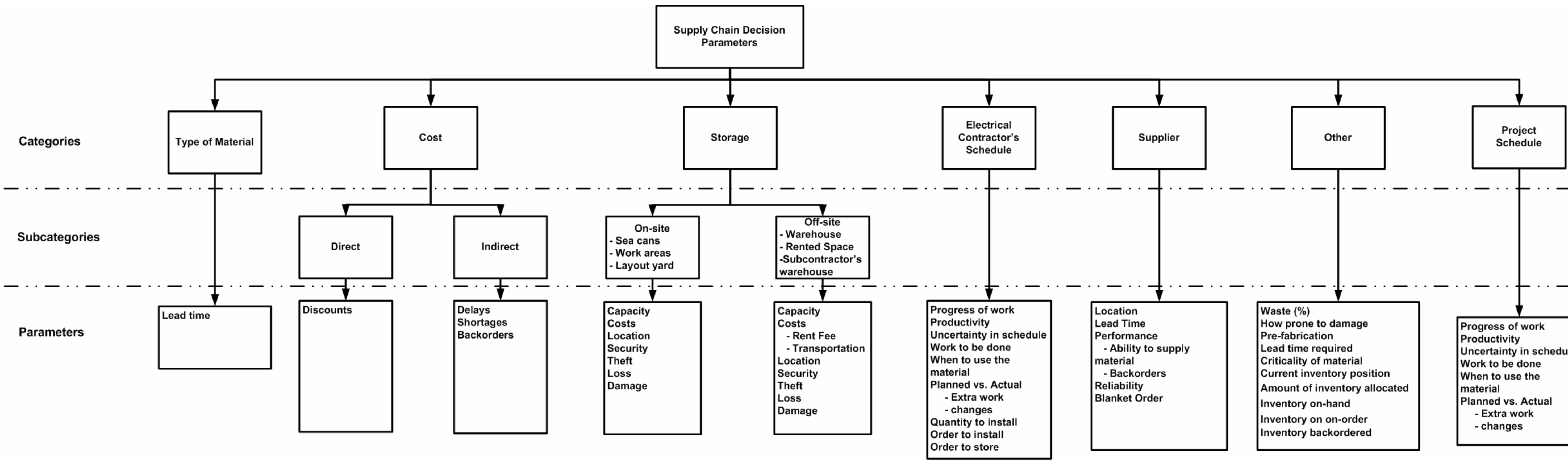

Figure 8.10: SPARCS for the When to Buy Decision

8.9 Summary

This chapter introduced and presented SPARCS, which is an acronym for **S**upply-chain **PAR**ameter **C**lassification **S**ystem. This classification hierarchy allows decision makers to classify supply chain parameters and organize them in a structured format, thus minimizing the time required for data extraction and reducing the tediousness of the current approach. The importance of developing such system was explained and the contribution of such system was described. The development of SPARCS fills the need for a structured model to categorize the parameters that need to be considered on the supply chain decision making process for the electrical contractor. SPARCS diagrams for all the decisions considered in the study where described and presented. For a more complete system design and model specification, a similar approach needs to be developed for alternatives and performance measures. However, the alternatives could vary between contractors and between the projects of a same contractor. Moreover, these alternatives could be input by the user when using the decision support model. The development of a structured approach for alternatives could be the basis for future research. However, this development will not affect or makes any contribution to SPARCS. The next chapter will present an example application on how such model would be used to assist a decision maker with material supply related decisions. Chapter 9 presents example application of the framework for a decision support tool for material supply management designed as part of this research.

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CHAPTER NINE: EXAMPLE APPLICATION

This chapter presents an example on how the designed framework could assist a decision maker with the amount of material to buy and where to get the material from. The general idea for the case has been adopted from the preliminary exam questions given by Dr. Ralph Badinelli and Dr. Julio Martinez. The name of the company used in the example is fictitious.

9.1 Example Case Study

JPR Construction, Inc. is a medium sized electrical contractor that specializes in commercial construction. The company specializes in two particular types of projects: data centers and computer labs. On average, 60% of the company’s contracts are for computer labs and 40% of the contracts are for data centers. Assume that the time between contracts is exponentially distributed with a mean of 5 weeks. Assume a total of ten projects for the year and that the average duration of a project is five weeks.

The management of the company believes that materials management is a very important aspect for successful project completion; therefore they focus greatly in material issues for cost control. Typically, the project personnel are in charge of buying the material needed. The foremen for each project are responsible for preparing the list of materials to be requested from the suppliers. The material requisition is sent to the PM who in turn, sends it to the purchasing department. This requisition specifies the type of material to buy, how much material to buy and where to deliver this material.

The type of material to buy is usually specified in the material schedule prepared in the pre-planning stage. Usually, the type of material to request, by the site personnel, is miscellaneous since major material is requested early due to the long lead times that it requires. The type of commodities to buy depends on the type of work expected to be done in the particular period. For example, the contractor needs to decide which type of conduit to buy (i.e. electrical metal tubing (EMT), polyvinyl chloride (PVC) etc.).

An item that is used in every project is 1” electrical conduit. The company has three options for obtaining the conduit required for their projects. The three options are buying from a supplier in Mexico, buying from a supplier in DC, or using a Vendor Managed Inventory (VMI) System. Purchasing a batch of conduit requires negotiating price with the supplier. For our case it is assumed that the supplier is already known and that the prices are already negotiated and fixed. The typical material requisition process starts on the construction side. The construction team fills a material requisition form specifying the material needed, quantities and dates when the material is needed. This form is sent to the project manager, who verifies the material requested and then forwards the form to the purchasing department. The purchasing department procures the material from the supplier and specifies type of material, quantities and delivery dates. Field personnel are responsible for inspecting the material upon receipt, rejecting any damaged material or wrong deliveries and forwarding the packing slip to the purchasing department for payment purposes. Once the requested material is received, the purchasing department is then responsible for processing invoices, and paying certain fixed freight costs.

If the material is purchased from a supplier, either D.C. or Mexico, there are costs associated with the procurement activities. These costs vary depending on the supplying source. The ordering of material is not an issue when dealing with the VMI system since it is the vendor’s responsibility to have the material available at the construction site. “Assume that at the end of the construction cycle any remaining material can be returned without incurring any additional costs due to restocking”. When ordering from Mexico or D.C., purchasing quantities are typically quite large and require a period of time from the moment that an order is placed to delivery to the specified location. Company policy dictates that the batch sizes are fixed depending on the supplying source. The company needs to place an order once the inventory reaches a certain level. This inventory level is known as the reorder point. The reorder point is set by another decision model that answers the question of when-to-buy. The how-much-to-buy decision and the when-to-buy decision are entangled. The conventional practice to solve these two problems separately was used, with the answer to the “how-much-to-buy” decision affecting the answer to the when-to-buy decision. Typically, materials managers determine how much to buy first. At this point in the decision process, the assumption that the reorder points are set in such a way that their impact on inventory holding cost and stockouts are within prescribed limits was made. The reorder points assumed for this problem could be changed by making an analysis of the when-to-buy decision.

Weather plays a factor for the delivery of the material and in certain instances it could delay deliveries. There is an additional cost associated with late deliveries. The majority of the times the material is delivered as ordered, however in minimal occasions the material needs to be rejected. This rejection creates an additional cost to compensate for delays in performance and reordering. Once the material is delivered, it is stored in the jobsite until needed. There is a cost associated with material being stored that is known as holding cost. The holding cost usually includes the lost investment income caused by having the asset tied up in inventory. This is not a real cash flow, but it is an important component of the cost of inventory.

If a Vendor Managed Inventory system is used, the distributor places a truck on site with the needed materials and equipment and maintains the inventory in the trailer throughout the project. The distributor charges the contractor for materials and equipment used at predetermined prices. The vendor visits the project at predetermined intervals. Every time he/she visits the project, parts are stored in the trailer and are available for future use. Table 9.1 depicts the data for the three options for material sourcing. The current batch sizes presented are based on the material requisition list prepared in the pre-construction planning phase. This batch size is set based on the anticipated productivity and work to be performed. The current service level is set up at 98% for all the options.

The construction firm uses the conduit on every project. This causes demand for the conduit to be fairly stationary. Recent time series analysis reveals that over all of the data center business that JPR, Inc. does, the average usage of conduit is 4800 pieces per week with a standard deviation of 900 pieces. For the computer lab business that JPR, Inc. does, the weekly usage of the conduit averages 3500 pieces per week with a standard deviation of 400 pieces.

Source	Mexico	D.C.	VMI
Procurement Cost ($/shipment)	$1280	$1025	-
Lead Time (weeks)	2	1	-
Unavailability Penalty ($/occurrence)	$250	$225	$300
Price ($/ 1" x 10'piece)	$1.59	$1.67	$1.80
Material Delivered as Ordered	95%	98%	95%
Rejection Cost ($/occurrence)	$250	$225	$200
Current Batch Size (# pieces/delivery)	30,000	20,000	10,000
Annual Holding Cost Rate (% of the average dollar value of inventory)	20 %	20%	-

Table 9.1: Data for the Three Options for Material Sourcing

9.2 Analysis of the Decision of "How-Much-to-Buy"

First let's consider the decision of how-much-material-to-buy. Based on the information given in the problem statement, the company currently orders in batches of 30,000 when ordering form Mexico and in batches of 20,000 when ordering from DC. The lead time for Mexico is two weeks and one week for DC respectively.

Figure 9.2 depicts the data extraction process for the how-much-to-buy decision, based on the framework described and explained in Chapter 7. This figure illustrates a descriptive model output in which the performance measures are computed for each of the alternatives listed. The user specifies the decision to make, in this case "how-much-to-buy". This decision is specified as an intelligent decision query. The parameters and other needed information is filtered from company records and other data sources and loaded into a temporary database that will be available while the analysis is performed.

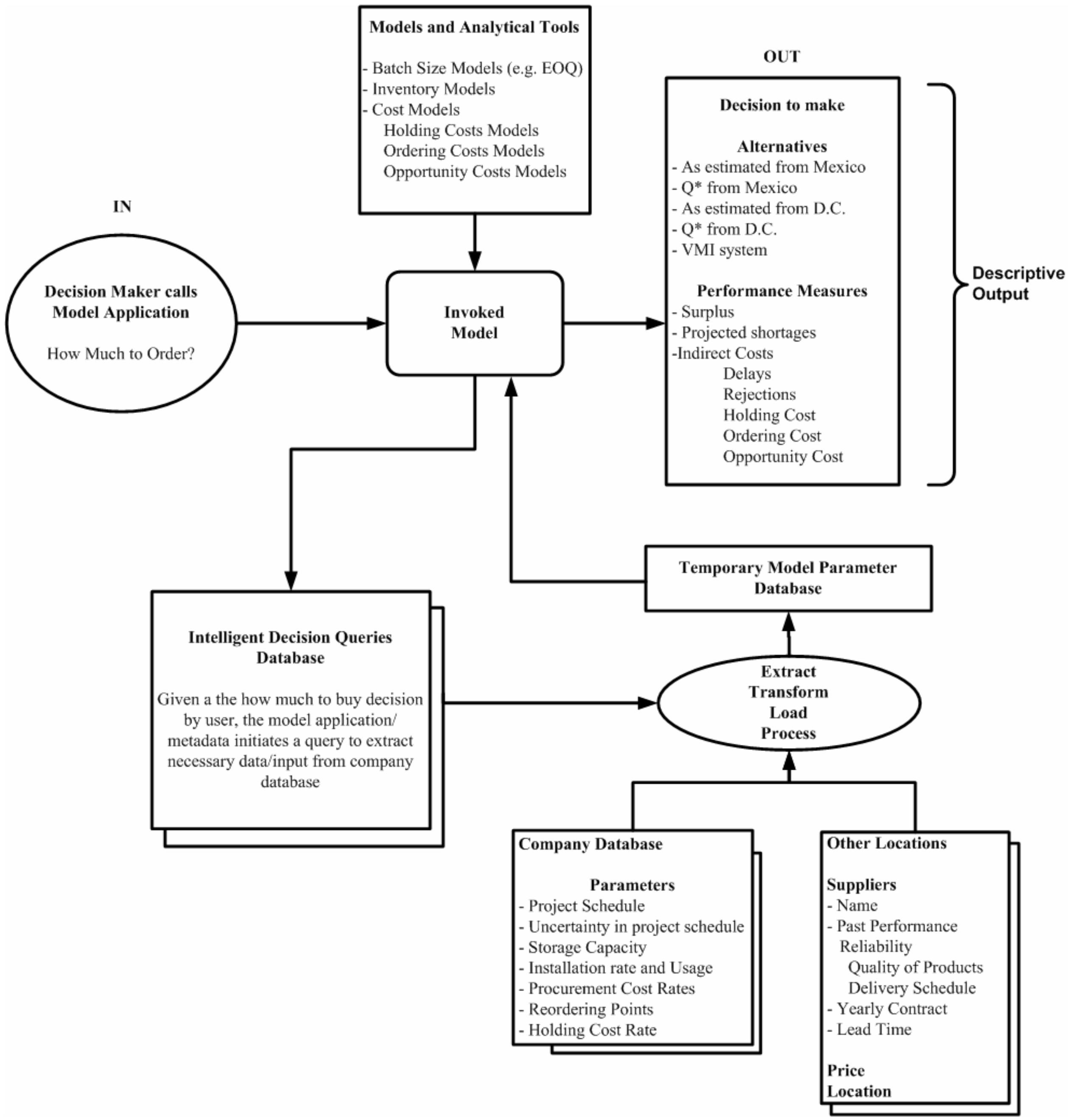

Figure 9.1: Data Extraction Process for the Descriptive Model for the How Much to Order Decision

Based on the information given, the alternatives for the how much material to buy include: buy as estimated from Mexico, buy as estimated from D.C., buy an optimal batch size calculated from the EOQ model from Mexico or D.C., or a quantity based on actual productivity. The parameters that could impact this decision were presented in

Table 9.1. Once this information is identified, analytical tools needed to perform the analysis for the particular decision are extracted from a database of analytical tools.

Analysis of Costs Depending on Batch Sizes

Model formulas are available that allow calculating performance of different batch sizes for each supplier. This section will present an analysis of costs for different batch sizes. The analysis will consider the actual batch size used by the company and a range of batch sizes to calculate the total costs.

Chopra and Meindl (2001) state that the optimal batch size (Q*) minimizes the total cost that is comprised by annual holding cost, annual material cost and ordering cost. They add that the annual holding cost increases with an increase in lot size and that the annual ordering cost decreases with an increase in lot size. It is assumed that the material cost does not change with an increase in lot size, although some discounts could be received based on quantity ordered. The annual holding cost and annual ordering cost are of equal amount for the Q*, therefore minimizing the total cost.

The formula used to calculate the optimal batch size comes from the Economic Order Quantity model (EOQ). The formula is as follows:

$$\text{Optimal Batch Size} = Q^* = \sqrt{\frac{2 * K * D}{h * C}}$$

Where:

K= ordering cost ($/per order)

D= average yearly demand = 214,000 in our case = (4800*0.6 +3500 *0.40)* 10 projects per year * 5 weeks per project

h= annual holding cost rate ($/$-year) = % of the average dollar value of inventory= $0.20 in our case

C= unit price of the item

This formula is applied to both the Mexico and DC suppliers to calculate the optimal batch size.

$$Q^* \text{ for Mexico} = \sqrt{\frac{2*1280*214{,}000}{0.2*1.59}} = 41{,}506 \text{ pieces}$$

$$Q^* \text{ for D.C.} = \sqrt{\frac{2*1025*214{,}000}{0.2*1.67}} = 36{,}241.8 \text{ pieces} \approx 36{,}242 \text{ pieces}$$

To perform the analysis of total cost, the annual holding cost and ordering cost need to be calculated. Chopra and Meindl (2001) state that the holding cost is "*the cost of carrying one unit in inventory for a specified period of time. It is a combination of the cost of capital, the cost of physically storing the inventory, and the cost that results from the product becoming obsolete*". The formula to calculate the annual holding cost is as follows:

$$\textit{Annual Holding Cost} = \frac{Q*h*C}{2}$$

Where:

Q = Batch Size

h= annual holding cost rate ($/$-year)

C = unit cost of the conduit

To calculate the annual ordering cost, the number of orders per year needs to be calculated first. The number of batches per year is calculated using the following equation:

$$\textit{Number of Batches per Year} = \frac{\textit{Yearly Demand}}{Q}$$

With the number of batches per year calculated, the annual ordering cost can be calculated. The following is used to calculate this cost:

$$\textit{Annual Ordering Cost} = \textit{Number of Batches per Year} * \textit{Ordering Cost}$$

The analysis of total cost for different batch sizes is presented in Table 9.2. As can be seen from Table 9.2, the batch size that minimizes the total annual cost for both options, D.C. and Mexico, is the Q* calculated with the EOQ model.

	Batch size	Number of Batches		Annual Ordering Cost		Annual Holding Cost		Total Annual Cost	
	(pieces/order)	Mexico	DC	Mexico	D.C.	Mexico	D.C.	Mexico	D.C.
	10,000	21.40	21.40	$27,392.00	$21,935.00	$1,000.00	$1,000.00	$368,652.00	$380,315.00
	15,000	14.27	14.27	$18,261.33	$14,623.33	$1,500.00	$1,500.00	$360,021.33	$373,503.33
	20,000	10.70	10.70	$13,696.00	$10,967.50	$2,000.00	$2,000.00	$355,956.00	$370,347.50
	25,000	8.56	8.56	$10,956.80	$8,774.00	$2,500.00	$2,500.00	$353,716.80	$368,654.00
	30,000	7.13	7.13	$9,130.67	$7,311.67	$3,000.00	$3,000.00	$352,390.67	$367,691.67
	35,000	6.11	6.11	$7,826.29	$6,267.14	$3,500.00	$3,500.00	$351,586.29	$367,147.14
Q* for D.C.	36,242	5.90	5.90	$7,558.08	$6,052.37	$3,624.20	$3,624.20	$351,442.28	$367,056.57
	40,000	5.35	5.35	$6,848.00	$5,483.75	$4,000.00	$4,000.00	$351,108.00	$366,863.75
Q* for Mexico	41,506	5.16	5.16	$6,599.53	$5,284.78	$4,150.60	$4,150.60	$351,010.13	$366,815.38
	45,000	4.76	4.76	$6,087.11	$4,874.44	$4,500.00	$4,500.00	$350,847.11	$366,754.44
	50,000	4.28	4.28	$5,478.40	$4,387.00	$5,000.00	$5,000.00	$350,738.40	$366,767.00
	55,000	3.89	3.89	$4,980.36	$3,988.18	$5,500.00	$5,500.00	$350,740.36	$366,868.18
	60,000	3.57	3.57	$4,565.33	$3,655.83	$6,000.00	$6,000.00	$350,825.33	$367,035.83
	65,000	3.29	3.29	$4,214.15	$3,374.62	$6,500.00	$6,500.00	$350,974.15	$367,254.62

Table 9.2: Cost Calculation for Different Batch Sizes

As expected, the annual ordering costs went down as the batch size increases for both cases. For Mexico, the annual ordering cost went from $9,130 for a batch size equal to 30,000, to $6,599.33 for a batch size equal to Q*. This represents a decrease in cost of $2,530.67. For D.C., there was a decrease in ordering cost from $10,967.5 for a batch size of 20,000 to $6,052.37 for a batch size equal to Q*. This represents a decrease in cost of $4,915.13. This is because larger, less frequent orders would decrease the fixed cost of ordering when compared to small, frequent orders.

The average cost of holding inventory per year went up in both cases. For Mexico, there was the annual holding cost increased from $3,000 for a batch size equal to 30,000 to $4,150.60 for a batch size equal to Q*. For D.C. the annual holding cost increase from $2000 for a batch size of 20,000 to $3,624.20 for a batch size equal to Q*. However, for both cases the increase compares favorably with the savings in ordering costs. In other words, the increase in holding cost is less than the savings in ordering costs; therefore the company could achieve some savings in total cost.

The analysis presented allows analyzing some aspects in terms of total annual costs, and pieces needed, between the two options. The alternative to be selected should minimize the total cost. The tradeoff to make is between the fixed order cost and the holding cost. From this analysis, it could be concluded that the best policy would be to order the Q* from Mexico. However, this calculation does not consider uncertainty and the costs associated with it for the three options. Therefore another model is needed to incorporate these uncertain parameters into the study and identify which would be the best option for acquiring the material needed, after the uncertain events are considered.

9.3 Reorder Point Model

The holding costs associated with ordering larger batches could be justified by availability of products, a desired fill rate that could be better than the small ordering policy. It can be expected that by ordering when the inventory drops to a certain level rather than ordering material per project, that there would less expected shortages per cycle. The inventory level used as a reference for placing an order is referred as the reorder point. The reorder point is the quantity required to meet demand during the lead time. Under probabilistic conditions, as specified in this example, there could be variations in demands and the reorder point includes safety stock. Safety stock is the amount by which the reorder point exceeds the expected lead time demand. The amount of safety stock determines the chance of stocking out during lead time. The complement of the chance of stocking out is called the service level. Service level is the probability of not having a stockout during lead time (Chopra and Meindl, 2001). The current service level for the DC and Mexico options was given. Figure 9.2 depicts the data extraction process for the calculation of the reorder points.

Having the values for the fill rates, the next step is to calculate the reorder points for the DC and Mexico options with the current batch sizes and the EOQ batch sizes. The formula to calculate the reorder point is:

$$\text{Reorder Point} = \text{Average Demand During Lead Time} + \text{Safety Stock}$$

The average demand during lead time is calculated as:

Average Demand During Lead Time = R*L

Where:

R= weekly demand

L= lead time

To calculate the safety stock, since the fill rate is given, the expected shortage per replenishment cycle (ESC) needs to be calculated. The formula that relates fill rates with the ESC is:

Fill Rate = (Q-ESC)/Q=1 - (ESC/Q)

Once the ESC is calculated, the formula that relates the ESC with safety stock is the following:

ESC= -SS *[1-NORMDIST(SS/STDL)] + STDL*NORMDIST(SS/STDL)

Where:

SS= Safety Stock

STDL= STDL= standard deviation during lead time = STD * SQRT (Lead Time)

NORMDIST= Normal distribution

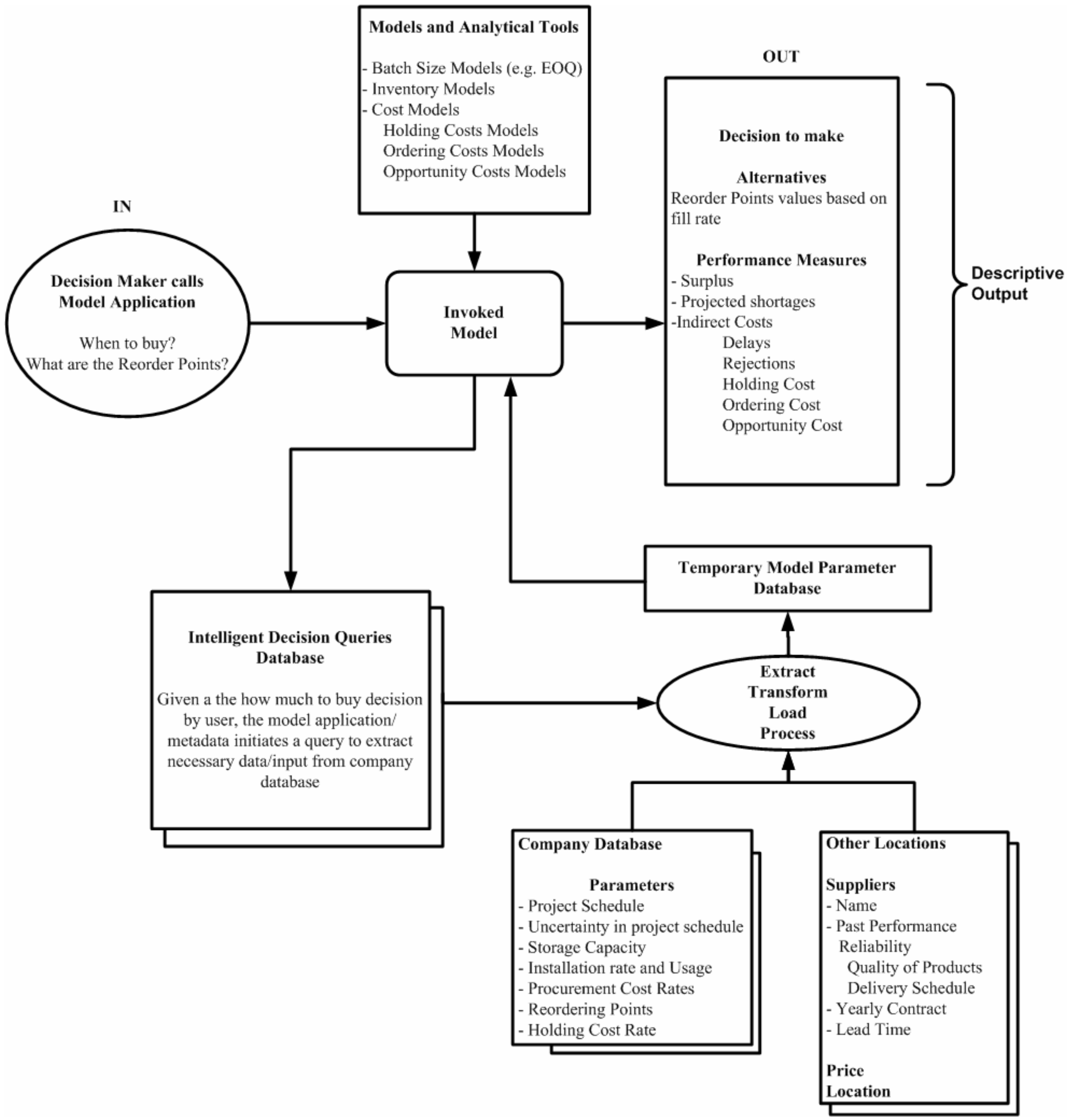

Figure 9.2: Data Extraction for Descriptive Model for the Reorder Point Calculation

This formula is solved for the SS by using iterations to solve for safety stock. The goalseek function in Excel was used to calculate the value for the safety stock.

Once the safety stock value is known, the reorder point is calculated. Table 9.3 summarizes the reorder point values calculated for the different batch sizes. Different values of fill rates are used to investigate which policy is better for the company.

Supplier	**Batch Size**	**Fill Rate**	**ESC**	**STDL**	**Safety Stock**	**Reorder Point**
Mexico	30,000	95%	1,500	1,273	-1,415	8,185
Mexico	30,000	96%	1,200	1,273	-1,055	8,545
Mexico	30,000	97%	900	1,273	-653	8,947
Mexico	30,000	98%	600	1,273	-175	9,425
Mexico	30,000	99%	300	1,273	490	10,090
Mexico	41,506	95%	2,075	1,273	-2,046	7,554
Mexico	41,506	96%	1,660	1,273	-1,596	8,004
Mexico	41,506	97%	1,245	1,273	-1,111	8,489
Mexico	41,506	98%	830	1,273	-551	9,049
Mexico	41,506	99%	415	1,273	198	9,798
D.C.	20,000	95%	1000	900	-930	8,670
D.C.	20,000	96%	800	900	-684	8,916
D.C.	20,000	97%	600	900	-409	9,191
D.C.	20,000	98%	400	900	-79	9,521
D.C.	20,000	99%	200	900	382	9,982
D.C.	36,252	95%	1,812	900	-1,805	7,795
D.C.	36,252	96%	1,450	900	-1,429	8,171
D.C.	36,252	97%	1,087	900	-1,031	8,569
D.C.	36,252	98%	725	900	-586	9,014
D.C.	36,252	99%	362	900	-7	9593

Table 9.3: Calculation of Reorder Points

The negative safety stock will decrease the reorder point. These reorder points calculated will be used in the analysis of the sourcing decision. From the table, it can be seen how the reorder point values increase as the fill rates increase.

9.4 Analysis of the Sourcing Decision

This section will analyze the sourcing decision or decision of from whom to buy. Based on the information given and the analysis in the previous section, the following alternatives will be considered, ordering the actual amount from DC and Mexico, ordering the Q* from DC and Mexico and using the VMI.

Once the decision is specified, the parameters are filtered from the parameter database. The sourcing decision and the how-much-to-buy decision are interrelated. The performance measures of the batch-sizing decision become parameters for the sourcing decision. The parameters for these alternatives, as gathered from the statement, are presented in Table 9.4.

	Parameters						
	Procurement Cost	Price	Unavailability		Rejection		Batch Size
	($/order)	($/piece)	Probability	Penalty	Probability	Penalty	
Mexico	$1,280.00	$1.59	3%	$275.00	5%	$250.00	40,000
DC	$1,025.00	$1.67	2%	$250.00	2%	$225.00	20,000
VMI	-	$1.80	2%	$300.00	5%	$200.00	10,000

Table 9.4: Parameters for the Sourcing Decision

Figure 9.3 depicts the data extraction process for the sourcing decision. Once the decision is specified, the analytical tools are extracted from the analytical tools database. The formulas used to calculate the total cost does not take into account uncertainties; therefore a more complete approach that considers the uncertainties needs to be used. The calculation that considers uncertainties will allow comparing the cost between all the alternatives without considering the uncertainty. In this case, the best analytical tool to analyze all the alternatives is to develop simulation models for the different alternatives.

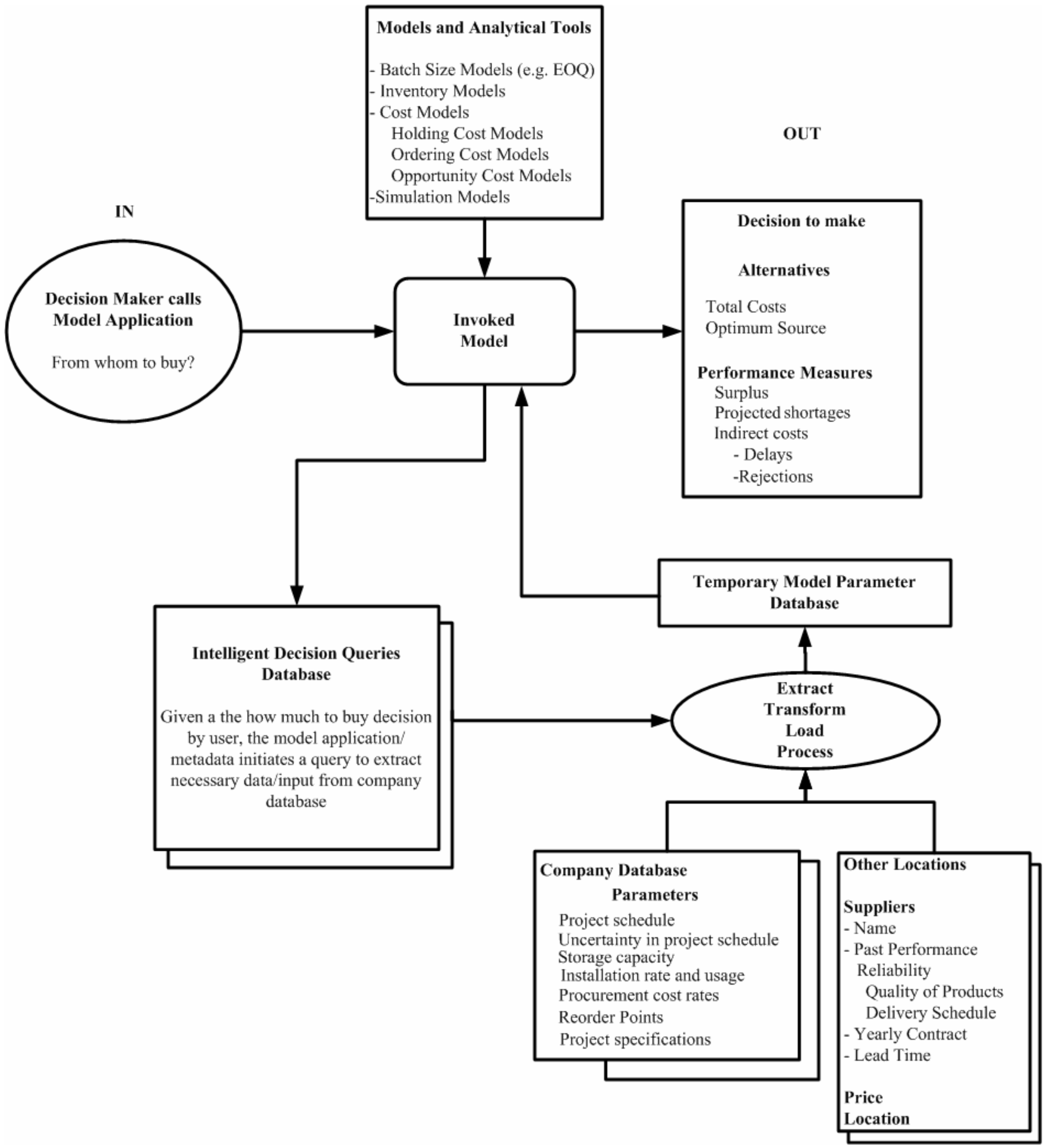

Figure 9.3: Data Extraction Process For the From To Buy Decision

For the case analyzed, the best tool to calculate the total cost is simulation. Discrete event simulation is a very useful tool for the design and analysis of operations because it can consider most of the uncertainties and logic associated with them. A simulation model allows including all the details needed to examine the different alternatives under the same conditions. By creating simulation models, the uncertainty and cost associated for all the alternatives can be considered. As mentioned before, formulas that we use for computing the reorder point are based on the probability distribution of demand during the lead time. Simulation allows us to model more complex effects of randomness than we can capture with formulas. Simulation tools exist that can model operations in detail (e.g. Pro Model, Stroboscope).

Among other factors, for these simulation tools to generate accurate results, accurate descriptions of the duration of all the activities or events and any other description, such as uncertainties, penalties, etc., need to be input.

Figure 9.4 depicts a flowchart that describes the simulation modeling approach used for analyzing the case study. The first step in the analysis is the calculation of optimal batch sizes by using the Economic Order Quantity (EOQ) model. This model provides the batch size that minimizes the total costs for ordering material depending on yearly demand, holding cost and ordering cost. All the batch sizes, the values presented in Table 9.1 and the values calculated with this model, will be then used to calculate total cost. The second step is to calculate the total cost for all the batch sizes considered, the batch sizes given in the problem statement and the ones calculated using the EOQ.

The material management decisions are related and the outputs from one decision are input to another decision as parameters or alternatives. For example, the batch sizes calculated in the “how-much-to-buy” decision will be used as inputs in the calculation of the total cost by using the simulation model. The simulation models consider the relation between the different materials management decisions. The starting inventory on the jobsite and the batch size ordered is equal to one of the alternatives from the decision of “how-much-to-buy”. The material installation process, labeled as 2 in Figure 9.4, consumes material from the inventory. This inventory consumption decreases the inventory level which is the parameter that triggers the decision of when to buy. Once the inventory level reaches the reorder point, use in that particular analysis, the material procurement cycle starts and an order to buy material is completed. The material procurement and delivery are included in the box labeled as 3 in Figure 9.4. The simulation of these processes considers any uncertainty in the events and whenever an uncertain event occurs, an additional cost or penalty, in the amount described in the problem statement, is added to the total cost. Once a project is completed, the model then does the same analysis for the next type of project to be completed. The simulation was run for a total of 10 projects, which represents a year worth of work for the company. The following sections will describe in detail the steps to analyze and calculate the total cost.

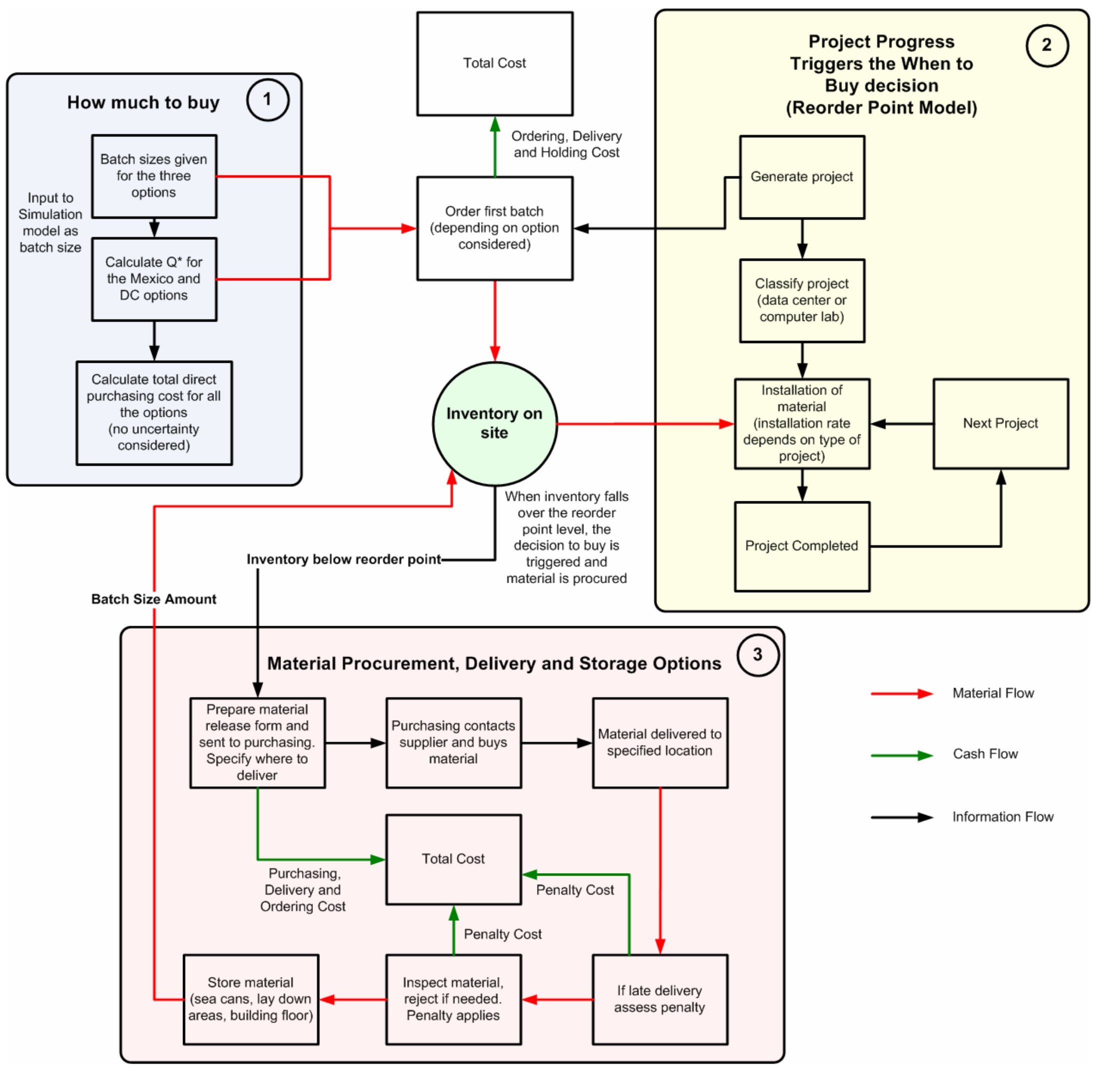

Figure 9.4: Flowchart of the Simulation Approach

9.5 Analysis of Results

The following section will present the analysis that would be performed, by using the analytical tools, to assist the decision maker in choosing the source for material procurement.

Simulation models were developed for the possible alternatives and considering all the parameters. Alternatives considered in the simulation study include: batch size equal to 20,000 from D.C., batch size equal tom 30,000 from Mexico, batch size equal to Q* for both Mexico and D.C. and the VMI system. For the purposes of the case study, the EZSTROBE (Martinez, 2001) simulation engine was used to developed and run the simulations. This environment allows considering the uncertain events that might have an impact in the decisions. In addition, it allows studying the alternatives under similar conditions. After the analysis was performed, a table was prepared, Table 9.5, with results for the different alternatives and their respective cost. Based on the total cost, including penalties, and other personal considerations the decision maker can select an alternative.

The simulation models for the alternatives are presented in Figures 9.5 through Figures 9.9. The simulation models were run for a total of ten construction projects. The same seed was used in order to compare the different methods under similar conditions.

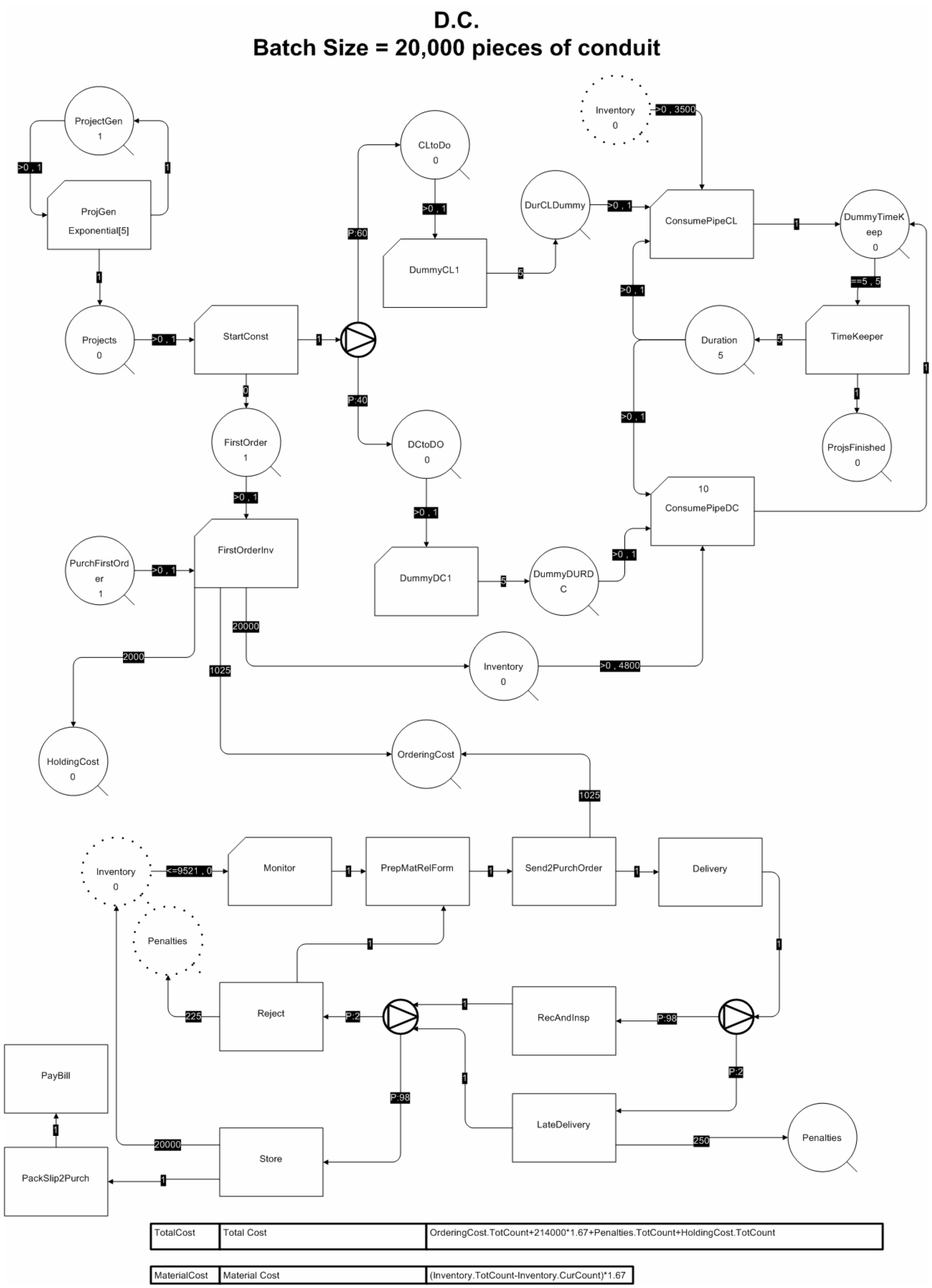

Figure 9.5: Simulation Model for D.C., Batch Size Equal to 20,000

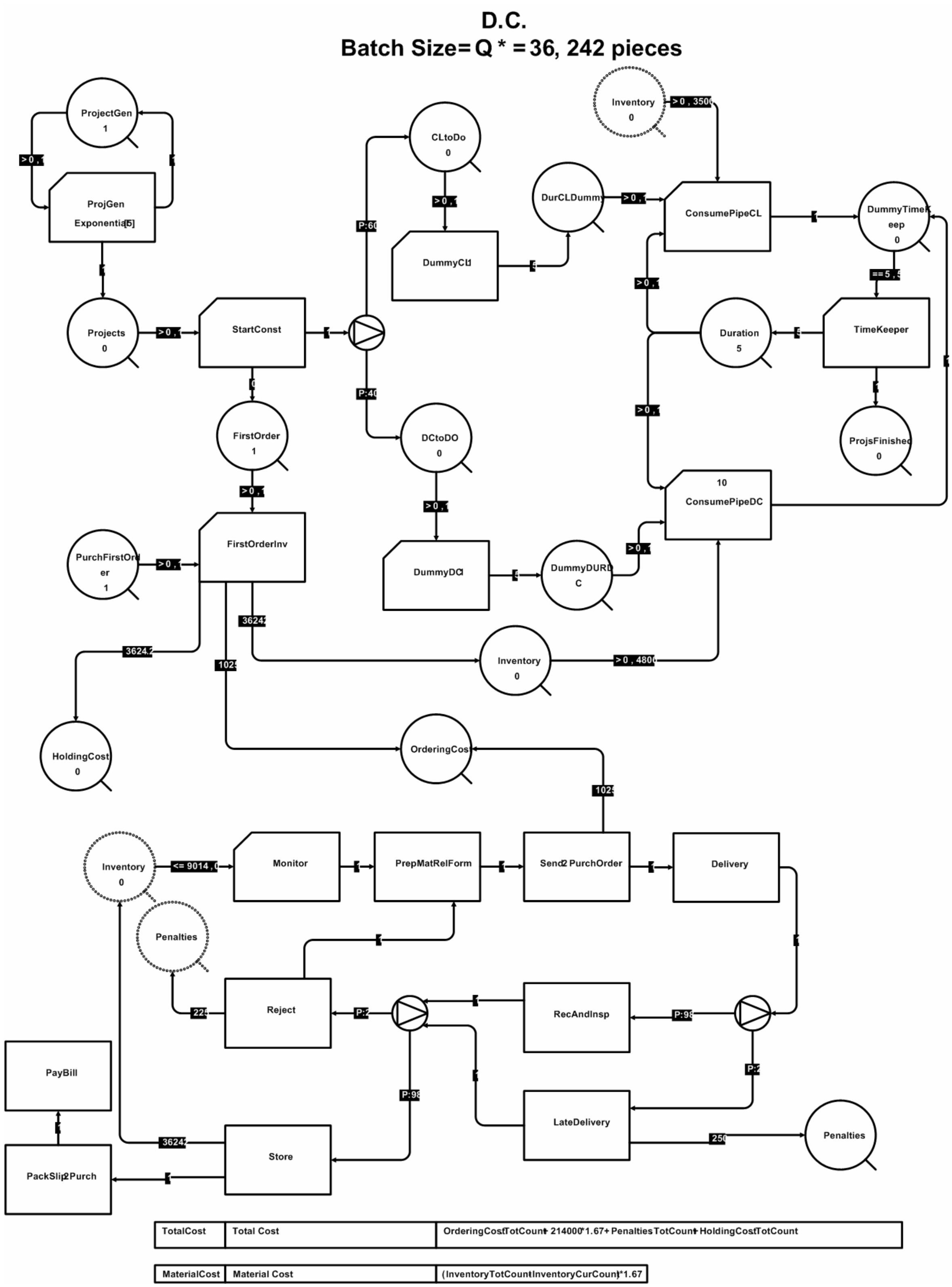

Figure 9.6: Simulation Model for D.C., Batch Size Equal to Q*

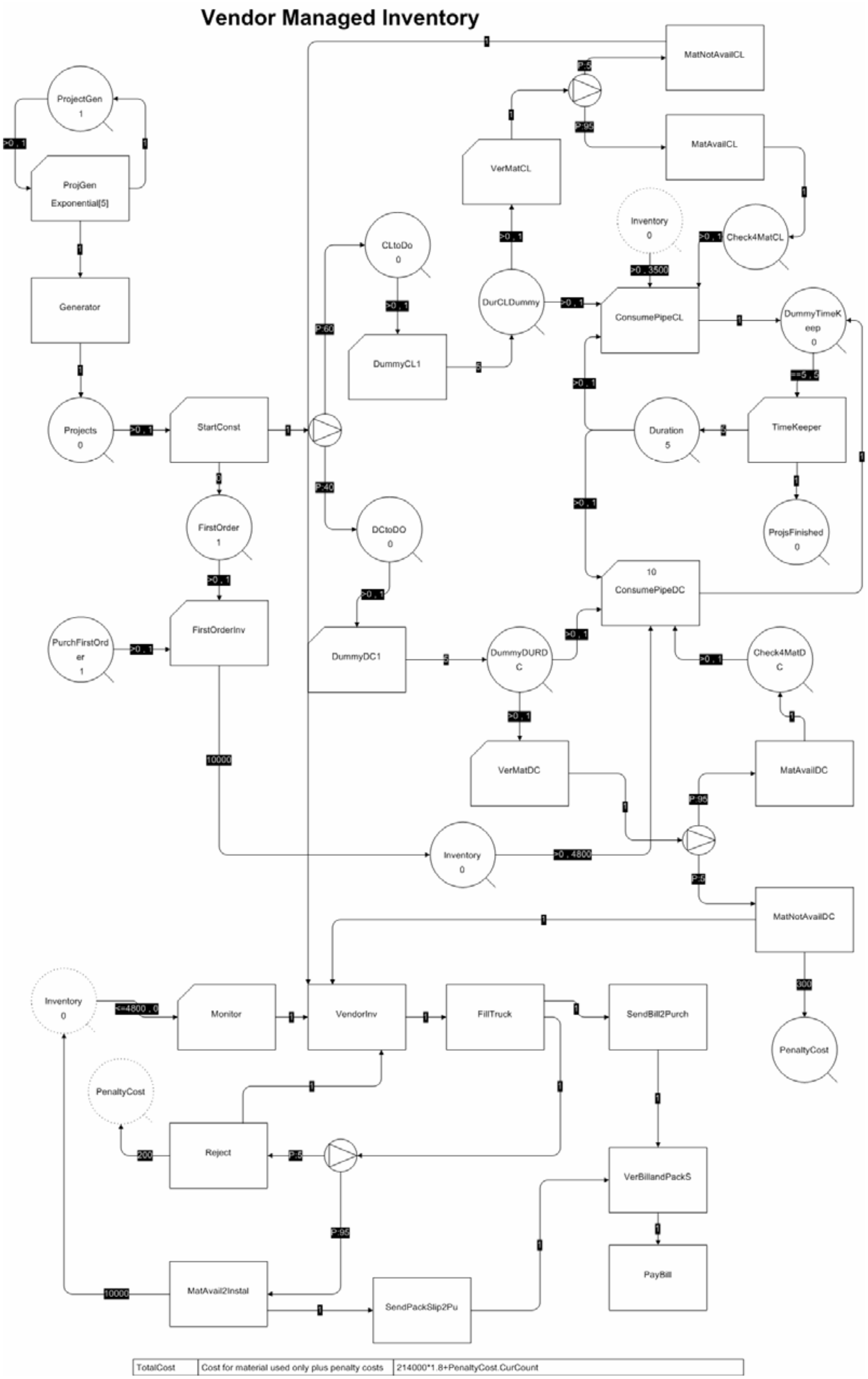

Figure 9.7: Simulation Model for VMI Option

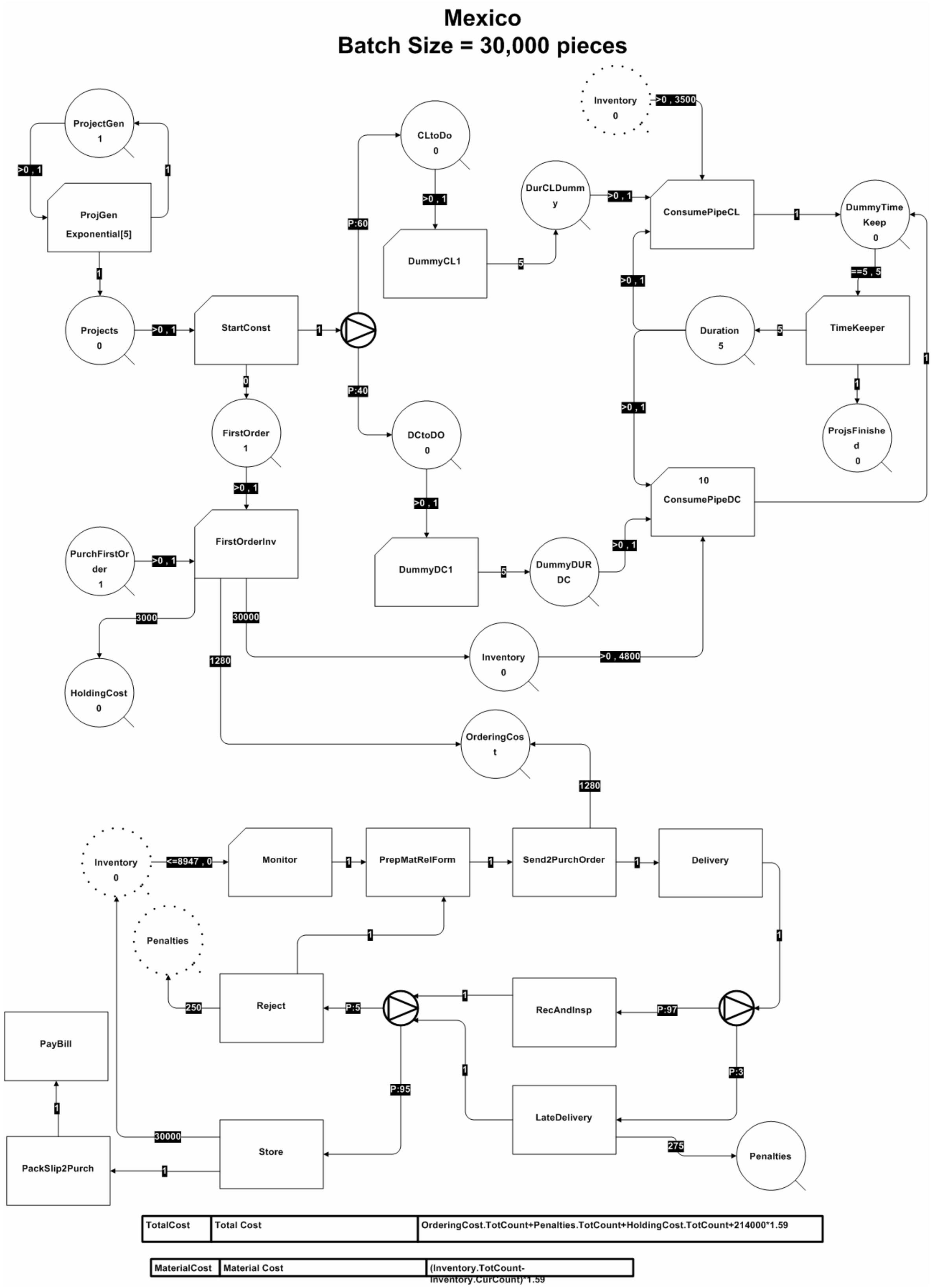

Figure 9.8: Simulation Model for Mexico, Batch Size Equal to 30,000

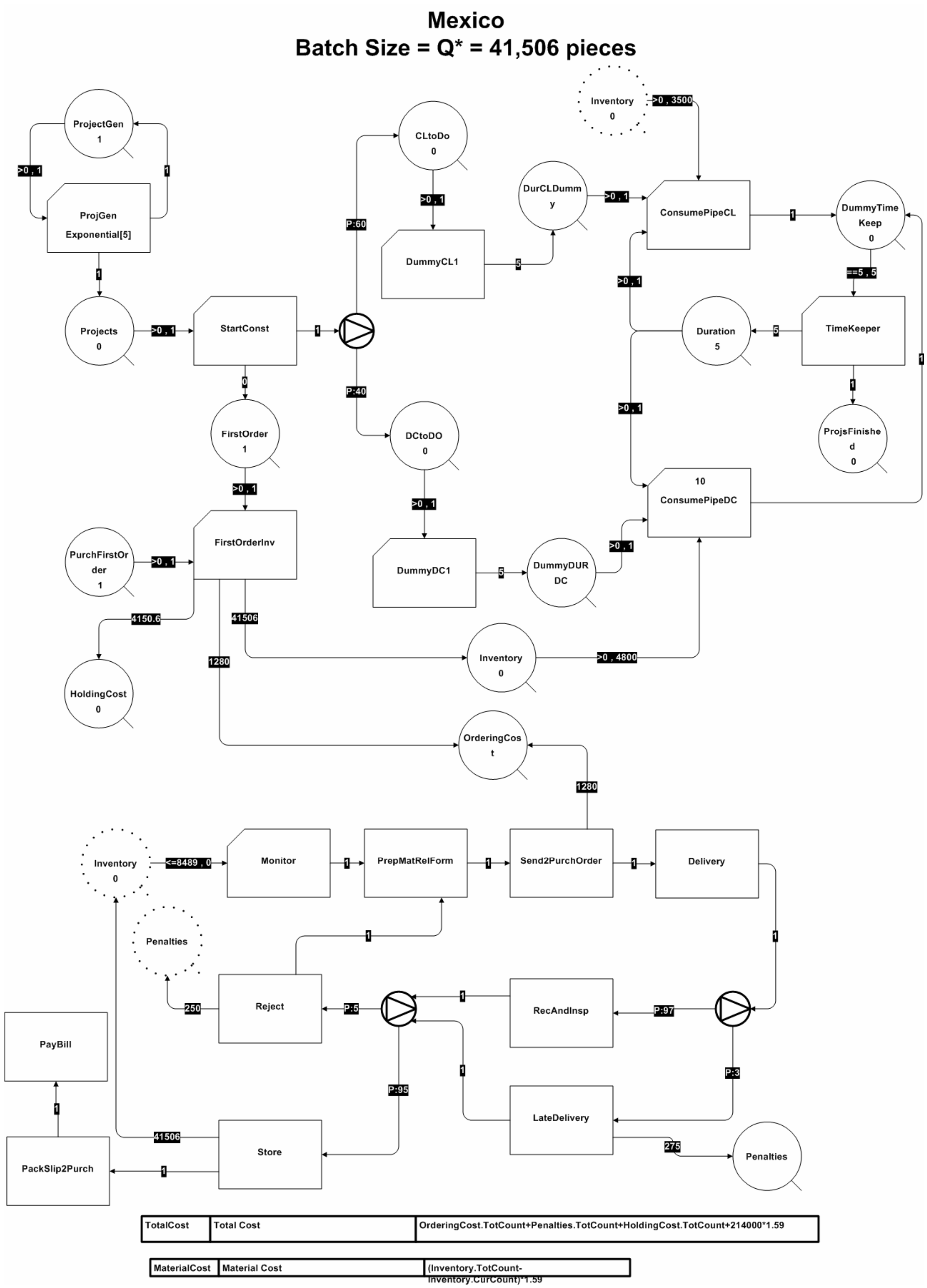

Figure 9.9: Simulation Model for Mexico, Batch Size Equal to Q*

Table 9.5 presents the total cost, including cost associated with penalties for late deliveries and rejections, for the different alternatives based on the conditions given. The total cost presented in this table considers the uncertainties and the cost associated with them. This analysis is needed because the formula based models do not allow including such uncertainties in the study. Simulations tools allow performing a more accurate analysis by quantifying the impact of uncertainties in the total cost.

	Total Cost	Penalty
DC- 20,000 Batch	$369,630.00	$0.00
DC -36,242 Batch	$367,154.00	$0.00
Mexico – 30,000 Batch	$352,495.00	$275.00
Mexico – 41,506 Batch	$350,825.00	$0.00
VMI	$385,500.00	$300.00

Table 9.5: Total Cost for the Alternatives Analyzed

Based on the parameters given in the problem statement and as can be seen from the table, the option that results in the lowest cost is ordering the Q* quantity from Mexico. The simulations were run with the different values calculated for reorder points. The negative values for safety stock mean that the reorder point goes down, thus changing the time when an order is placed. The onsite material is enough to cover the lead time demand; therefore no extra penalties for unavailability of material are expected and the total cost was the same for all the fill rates. The same seed was used in all the options. The contractor might consider buying from other supplier even though the price might be higher, if the material availability is very critical for the project. The VMI option presents a higher total cost for the contractor in terms of material. This is because the unit cost for the material is much higher. This is one of the reasons why this method is not commonly used.

The simulation models developed would easily allow performing other types of analysis such as changes in costs that are expected. In addition, the models would allow a decision maker to calculate for which material cost, he would be indifferent in buying from any of the sources.

This chapter presented an example application on how the framework designed could be used to analyze decisions related to material management. The example presented dealt with the amount of material to buy and from whom to buy the material from. Many other decisions could be analyzed following the information presented in this document including the framework presented in Chapter 7 and SPARCS in Chapter 8. The implementation of SPARCS and the framework could be very helpful for a decision maker. However, in order to quantify the possible benefits of the system, it should be further developed and subsequently implemented in an actual construction company.

9.6 References

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CHAPTER TEN: SUMMARY AND CONCLUSIONS

10.1 Summary

Through out the document, material management for the construction industry has been analyzed and described. This study was done in an effort to improve the current material management practices for the construction industry. Chapter 1 presented the research statement. This chapter presented a description of the problem statement, the objective of the research, the justification for the research, the methodology for the research work, relevance of this work to the construction industry and the limitations of this study. Chapter 2 presented a general introduction to material management in construction. This chapter defined what a material management system is, typical materials used in the construction industry, why is important to have a material management system and the advantages of having it. Chapter 3 presented the current state of knowledge in material management for construction. This chapter described other research efforts that have been performed in material management for construction. These studies were classified into materials management and project management, benefits and costs of a materials management system, role of vendor/supplier and fabricator, models developed and studies of effectiveness of materials management, use of technology for materials management, other research related to materials management, materials management for the electrical contracting industry, cultural change in construction, supply chain management for the manufacturing industry, and knowledge management. Chapter 4 presented an overview of the electrical contracting industry including services provided by electrical contractors, materials purchasing by electrical contractors, and typical products used by electrical contractors. In addition, this chapter described the current material management practices in the electrical contracting industry including current materials management practices in the electrical contracting industry the different phases: bidding, sourcing, material procurement, construction and post-construction. This chapter also described supplier/contractor arrangements such as partnering, among others. Chapter 5 described the many challenges that are encountered during the five phases of the materials management process. These challenges were grouped into three categories: information technology, decision modeling and implementation management. Chapter 6 presented the decision modeling approach used in the study. The chapter gave an introduction to decision modeling, described the modeling approach used and explained the decision making processes studied. Chapter 7 presented the framework for a Decision Support System (DSS) for material supply chain. The chapter provided a description of the decision making process for material supply chain for the decision nodes considered: what material to buy decision node, how much to order decision node, when to buy material decision node, when to deliver material decision node, where to deliver material decision node, where to store on site decision node. In addition, the chapter provided a description of framework for decision models. Chapter 8 provided a description of SPARCS - Supply-chain PARameters Classification System. The chapter describes the development of SPARCS, the data definition for SPARCS, and the application of SPARCS to all the decisions considered in the study. Chapter 9 presented an example application of the framework and how it could be used to decide the source for material supply. The example presented is fairly comprehensive and describes in detail how the model would work once implemented in a computer application.

10.2 Conclusions

Efficient material management is crucial for the success of any construction project and can be the deciding factor between a successful project and a project full of delays and claims. Better material management methods and decision models are needed to improve the electrical contractor's current practices, thus increasing efficiency and minimizing costs. An effective material management system is essential to avoid material shortages, misplacements, loss, and theft which might result in increases in crew idle times, loss of productivity and delay of activities. Electrical contractors should implement an efficient material management system due to the fact that in most of the cases they are asked to squeeze their bids in order to keep the costs of project under budget. In such a case, failures to effectively manage materials could result in decreases in profit or even a loss. The primary goal is to have the material needed, in the amounts needed, with the quality required, and the time that they are needed. Most electrical contracting companies have a material management system that serves their needs, although it could be improved. Standardization of the material management system could be a step forward in improving the sys-tem and eliminating some of the bottlenecks.

The research presented in this document aimed at designing an integrated system of decision-support tools for material procurement for the electrical contractor. An integrated approach for material procurement provides better decisions on what to order, how much to order and where to deliver. Future research will be needed to develop a more complete framework integrating other decisions needed in areas such as supplier selection and preliminary material scheduling during the pre-construction phase. A fully integrated approach will better improve communication and minimize gaps in information flow among all the parties and departments involved.

10.3 Contributions

The main objective of this research was to improve the decision making process for supply chain management in the electrical contracting industry. The work presented in this document, constitutes a contribution to the body of knowledge. This was accomplished by the identification of bottlenecks in the supply chain management process and the development of a new decision model for the EC industry. The contribution presented in the study is comprised by the following components:

1. The development of structured systems design of distributed, integrated decision support systems for supply chain management for the electrical contractor. This was accomplished by the work presented in Chapter 7.
2. The identification of the current material management practices for the electrical contracting industry and the representation of these practices in a graphical way by the development of the flowcharts presented in Chapter 4.
3. The identification of decision nodes in the current material management practices for the electrical contractor. More specifically, identifying which are the important questions and aspects related to decision making for material supply chain in the electrical contracting industry. These decisions are described in Chapter 6.
4. The definition of the data, models, decision makers and procedures that make up the knowledge and a mapping of their relationships is another contribution of this study. The data collection and description of current practices is explained in Chapter 4.
5. The development of SPARCS described in Chapter 8.

6. The design of the framework for material supply chain for the electrical contractor described graphically in Chapter 7.
7. This research breached some of the barriers to the adaptation of methods and technologies that are emerging in other industries by working with companies from the electrical contracting industry in the design of the framework for implementing supply-chain practices. The interview process was described in Chapter 4.

10.4 Directions for Future Research

This research established the knowledge and bases that allow re-engineering the current practices for material supply chain management for the electrical contracting industry. The research provides a framework for the design of a decision support system to assist the decision maker in the construction phase of the project. The implementation of the framework will allow making better decisions on what material to buy, when to buy, where to deliver, where to store. This research didn't consider the entire issues in the supply chain management for the electrical contracting industry; however, it serves as the basis for future research in the area. This section presents research directions and issues that could be the basis for future research efforts.

Expand the Framework to Include Other Phases of the Material Management Process

The framework developed, at part of the research, is limited to addressing the decision models for material ordering and delivery options during the construction phase. The framework could be expanded to consider and include other phases of the construction process such as material estimating and preparation of the material requisition projection, supplier selection and material surplus handling. The consideration of all the phases of the material management system will allow a more integrated and holistic approach to the material related activities in a construction company.

Database Design and Development for the Knowledge Elements

The decision nodes identified in this research are considered as independent decision systems, therefore the data required by every decision system was identified independently from the other systems. However, most of the knowledge elements are common data used across the different systems. Future research should combine the results of this research and design a database for all the knowledge elements required for material supply chain. This development should consider the design features of existing software and databases that are used in other industries for supply chain management in order to specify the better adaptation of this information technology to supply chain management for contractors. This design should include the application of standard methods for data definition and the construction of entity-relationship diagrams (ERD). Finally, the decision support systems specified for SCM in the construction industry should be able to integrate with ERP systems, thus allowing the extraction of data for each decision model from the system.

Expand SPARCS into a Knowledge Map

SPARCS, as described in this document, is a system that allows categorizing parameters for material supply chain. By expanding SPARCS to be a knowledge map, it would define all of the knowledge elements of the decision support system including the decision variables, performance measures, formulas, optimization routines and human expert knowledge that are involved in the decisions.

Expand the Framework to Better Represent the EC Industry

The framework designed as part of the research concentrates mostly in commercial construction. The interviews conducted focused on medium size contracting companies. The framework should be expanded to

- include other types of work such as residential, industrial, government work among others
- consider bigger size companies, in terms of volume of sales per year
- include companies from other geographical areas

Development of the Framework into a Computer Program

The document presented the design of the framework for a decision support system for material supply, but developing a computer application, for the framework designed, was beyond the scope of this research. Further research can focus in the implementation of the design specified in this document in the development of a computer application of decision support system. This development will require computer programming in Visual Basic or C++. The database design and development for the knowledge elements, presented earlier, should be accomplished prior to the development of the computer application. In addition, the expansion of SPARCS into a knowledge element should be accomplished prior to starting the effort of developing the computer application. This will allow the computer application to extract the data needed in the analysis from a previously defined database incorporated into the company's ERP system.

Figure 10.1 depicts the setup for the implementation of the decision support framework into a computer model, as well as the extraction process for the data (e.g. parameters) and models (e.g. inventory models, simulations models, etc.) needed to assist the decision maker. The decision support model, per se, is a computer program as opposed to data. In a knowledge map, this program can be recognized as a file that is stored either on the decision maker's computer or on the company's server.

The user calls the model application (1). The user selects, from a menu, the decision to be analyzed. This selection is specified as an intelligent query. This definition allows filtering and extracting the model parameters needed for a particular decision from all the data available in the company's database (2). The model parameters needed for the analysis are filtered and extracted from their permanent storage locations in the company's database or other locations such as supplier servers, internet resources, etc. (3). Once extracted, these data are loaded into a temporary location for the running of the model (4). These data are all temporary data elements that exist while the model is being used for the specific user call initiated. The model calls the necessary analytical tools that utilize the temporary data elements to provide the better decision at that particular instant. These analytical tools are filtered using the intelligent query defined for the particular decision (5). Once the model runs and provides a decision support for the user (6), including performance measures and alternatives considered in the analysis, the knowledge elements stored in the temporary database are erased.

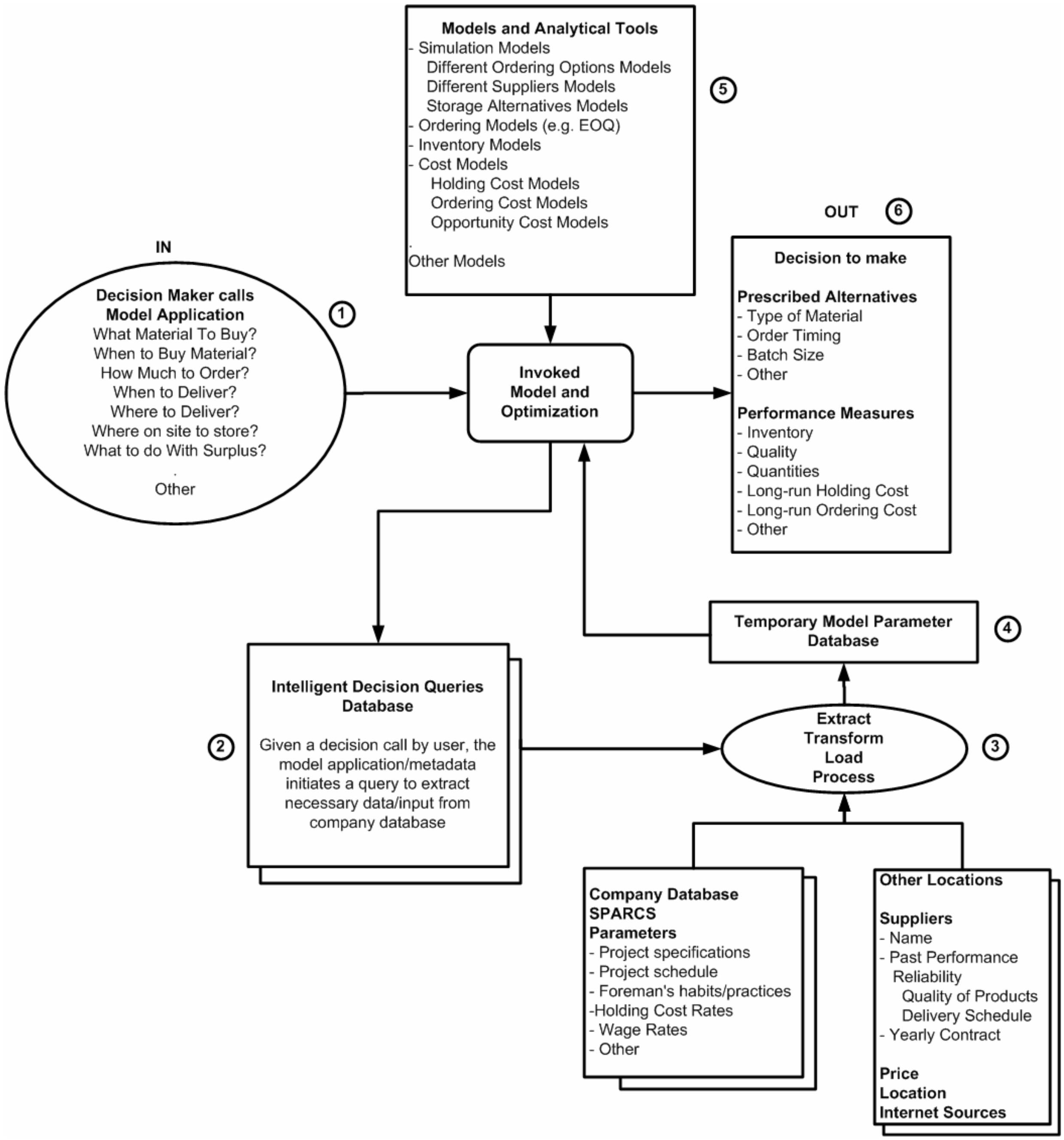

Figure 10.1: Setup for Computer Implementation

Implementation of the DSS in a company

Implementation of the model in the field is essential for quantifying the accuracy of the model and to identify gray areas that need refinement and a closer analysis. The use of the model in construction companies will enrich the refinement process and improve the analysis of areas that need further review. Input from construction companies is essential for the successful refinement of the model. Based on these input obtained from companies, problematic areas that need further review and improvement can be identified, analyzed and modified. In order to implement new strategies on the model, a close look to the entire process is needed. The effects that the new strategies could have in existing strategies and in the overall process should be identified and appropriately addressed. This analysis and subsequent refinement of the model can be accomplished by subsequently implementing the model on the field and monitoring of the accuracy of the model.

Build an Implementation Plan for the Decision Support System

The construction industry has been underexposed to the progress made in the manufacturing economy in SCM and decision support systems of the last decade. Given the fragmentation of the construction industry and the resisting culture encountered, a detail implementation plan of the decision support system should be develop. This implementation plan should address the areas that could concern contractors such as computational requirements, educational requirements, monetary requirements and collaboration requirements for successful implementation.

Study Cultural Change Issues

The construction industry is very resistant to change. The "*if it is not broken, don't fix it*" attitude is typical in this industry. Implementation of new innovative methods might be difficult in such an environment. Riley and Clare-Brown (2001) cite the Royal Academy of Engineering that states that *"the challenge of changing the culture in the construction industry … is daunting."* Therefore a study of the culture encountered in construction is essential for the implementation of the decision support system in a company. The study should develop guidelines to assist with cultural issues that resist change and to incorporate the decision models in the Electrical Contracting Industry (i.e. what to do with field/office personnel to adopt the new model). Some of the following should be considered for the development of an implementation plan in an actual company:

- Corporate or "head office" based
- Construction project based

- Coordination and information sharing between the electrical contractor and general contractor
- Coordination and information sharing between the electrical contractor and the supplier.
- The electrical contractor as a procurement specialist – a new role and new education requirements
- The electrical contractor as a supplier with an inventory of his own for some items.
- The use of new IT for supply chain management by electrical contractors and by general contractors.
- A higher level of investment in supply chain management (IT, training, and personnel) than the industry has made in the past.

Incorporate Existing Tools and Technologies to the Developed Framework

Existing technologies (i.e. web based methods, Pocket PCs, bar codes, RFID) could be very useful to effectively manage the materials management process. Automation of the process can be very beneficial for all parties involved. By automating the process, manual entries can be minimized, thus minimizing errors associated with materials inventory and control. This could be accomplished by using bar codes or RFID systems that can automatically gather inventory information in an electronic format, instead of manually registering inventory information. This eliminates double entries. Moreover, material related data can be gathered at a much faster rate using bar codes or RFID, instead of manual methods, and errors in data collection can be greatly reduced. The challenge lies on the implementation of such technologies along with the framework described in this document.

Implementation of the DSS in other Construction Sectors

The construction industry is moving towards fragmentation and it is safe to say that in a typical construction project more than 80% is performed by specialty contractors. All sectors of the construction industry share a common ground for material management and control. Therefore, the concepts described in this document could be easily applied to other sectors to build industry specific decision support systems for material supply chain.

10.5 Closing Thoughts

The manufacturing industry has successfully applied material management systems for the last decades and this has been possible by the enabling culture change that exists in this industry. There are movements in the manufacturing sector towards Just in Time (JIT), Total Quality Management (TQM) and enterprise resource planning (ERP), among others, that support the claim that there is an enabling cultural change. Unfortunately, the construction industry is very resistant to change. The "*if it is not broken, don't fix it*" attitude is typical in this industry. Implementation of new innovative methods might be difficult in such an environment. However, the construction industry is being pressured by competition, owners and the overall market to be more effective, more responsive, more efficient and to provide more value by reevaluating its methods and processes. Most contractors are small business owners who cannot afford to design their own systems. In addition, if every contractor is developing there system independently, this would produce many incompatible systems. Standardization and institutionalization of new methods and processes are especially important in the construction industry.

It is clear that effective planning is required to keep costs to a minimum and to insure that the material is on site when needed. Poor planning of materials will increase indirect costs associated with delivery and use of materials. In addition, losses in productivity, delays, re-handling, and duplicate orders among other factors can be expected when there is a poor materials management system. The electrical contractors need to realize that by improving their material management systems improvements could be achieved in other areas such as in the labor force. The effects of not having material available when needed are could be difficult to measure, but the impact in labor productivity could be noticed and quantified. Indirect labor cost due to absence of materials could be significant. Increases in idle time and/or unproductive time should be expected. Crew members will pretend to be busy even if there is no material to install, which increases the labor cost.

Stukhart, G. and Bell, L.C. (1987) conducted a study of twenty heavy construction sites where the following benefits from the introduction of materials management systems were noted:

- In one project, a 6% reduction in craft labor costs occurred due to the availability of materials on site when needed. On some other projects, an 8% savings was estimated by reducing the delay for materials.

- Two projects, with and without a materials management system, were compared and the comparison revealed a change in productivity from 1.92 man-hours per unit without a system to 1.14 man-hours per unit with a new system. Much of the difference can be attributed to the timely availability of materials.
- Warehouse costs were found to decrease 50% on one project with the introduction of improved inventory management, representing a savings of $ 92,000. Interest charges for inventory also declined, with one project reporting a cash flow savings of $ 85,000 from improved materials management.

Other issues that could be a consequence of a bad material management system include disruptions of work flow, time lost due to relocation of the work force, changing set ups to new locations where material is available, even if it is different activity, de-motivation of supervisors and possibly labor force. On the other hand, excess of material due to early deliveries could disrupt the work flow, require re-handling material to free up space for other crews to work, which requires time, the possibility of material being damaged increases and there is a greater probability of having accidents due to extra material on the jobsite.

10.6 References

O'Brien, K.E., (1999), "*Improvement of On-Site Productivity*", K.E. O'Brien & Associates, Inc., Toronto, Ontario, Canada

Riley, M.J., Clare-Brown, D., (2001), "Comparison of Cultures in Construction and Manufacturing Industries", *Journal of Management in Engineering*, Vol. 17, No. 3, pp. 149-158

Stukhart, G. and Bell, L.C. (1987), "Costs and Benefits of Materials Management Systems," *ASCE Journal of Construction Engineering and Management,* Vol. 113, No. 2, pp. 222-234

Appendix A: Questionnaires

Questionnaire A

Suppliers

- What type of materials do you supply?
- Typical process to place an order by a customer? (i.e. visit the store, phone)
- Once the order is placed, how it is processed?
- Do you use any computers to process the orders?
- Who monitors the process?
- Do you use any technology (i.e. bar codes, EDI, RFID) for inventory control?
- What happens if you don't have the quantity required by the customer?
- Do you have many customers asking the price matching?
- Do you do pack all the materials needed by a contractor in a pallet and have them ready for pick up by the customer?
- Do you do JIT delivery?
- How effective is your delivery in terms of time and quality?
- What are the major problems that you can identify in the system? (i.e. delivery times, quantities, relations with customers)

Contractors

- What is the type of materials that you usually buy from suppliers?
- How do you typically place an order? (i.e. visit the store, phone)
- Who monitors the process and makes sure that the materials will be on site when needed?
- Do you use any technology (i.e. bar codes, EDI, RFID) for inventory control on site?
- Do you typically pick your materials or you like the supplier to deliver them?
- Do keep inventory in site?
- Do you use JIT delivery?
- How effective is the delivery of suppliers in terms of time and quality?
- What are the major problems that you can identify in the system? (i.e. delivery times, quantities, relations with suppliers)

Questionnaire B

Storage Process

- Where are the materials stored?
- How do you keep track of materials installed/remaining? Tie with the stock requisition question

Inventory

- Who manages the on-site inventory?
- Does the distributor provide an on-site truck?
- Does the supplier provide inventory management?
- Based on what you schedule a materials release?

Materials Handling

- What are the major difficulties when handling material on-site?
- Who is in charge of the materials handling plan and procedures?
- Based on what you move materials to the site?
- How often do you move materials to the site?
- What happens if there are problems with materials shortages or materials damaged?

Problem Areas

- What do you think are the bottlenecks?
- Any suggestions for improvement?

Questionnaire C

General

- Do you have a classification for materials? Can you provide examples?
  - Bulk
  - Engineered
  - Fabricated
- What are the major problems that you can identify in the system overall? What is the major problem that you fill has to be fixed? Can you elaborate on major issues?
  - delivery times
  - quantities
  - quality
  - relations with suppliers

How to order material

- What are the types of material that you usually buy from suppliers?
- How do you typically place an order? Give examples? Is the process different for different type of materials?
  - Visit the store
  - Phone
  - Fax
  - E-mail
- Problems associated with the ordering process?
  - Lost of order
  - Fax not received
  - Too many papers to fill out
  - Not a good definition of what is wanted
  - Poor communication with supplier
  - Vague stated requirements
  - Materials not available

- Do you typically pick your materials or you like the supplier to deliver them? Which type of materials you must likely pick up? Which type of materials would you prefer be delivered to you?
- Who follows up the order and makes sure that the materials will be on site when needed?

How to qualify suppliers

- What are the procedures used to evaluate potential suppliers?
    - Forms
    - Experience of supplier
    - Reputation
    - Previously worked with the supplier
- What are the typical problems associated with the qualification process?
    - Time taken for the qualification process
    - Too many suppliers to qualify

Quality Issues

- Quality is specified in the specifications for a particular project. In order for approval of the work, the contractor has to meet the quality requirements specified. How are quality issues specified to the supplier?
    - Copy of specifications
    - Orally
- Sometimes when materials arrive to the site, they are not exactly what you order or don't meet the requirements specified. What are the typical problems associated with quality issues?
    - No supplier QA
    - Materials don't meet the required quality
- The contractor has to tell the supplier the quality expected and the tolerances for the materials. How are inspection procedures specified to the suppliers? Are the inspection procedures different for different type of materials?
- Typical problems associated with inspection procedures
    - Procedures not followed
    - Non conforming items not identified

    - Non conforming items not isolated
- Typical problems associated with received materials from suppliers? Can you provide examples?
    - Lack of conformance to requirements
    - Quality problems
    - Damaged materials
    - Non-conformance with requirements
    - Late deliveries
    - Incorrect type of materials delivered
    - Incorrect sizes delivered
    - Incorrect quantities delivered
    - No supplier QA

Storage

- Do you keep inventory on site? If you do keep inventory, which materials are the most likely in your on site inventory? Which materials will never be in your inventory on site?
- How adequate are procedures for storage material on site?
- Different things can happen to materials once it is stored on site due to weather, human factors, etc. What are the typical problems that you can associate with stored material?
    - Not adequate space for storage
    - Theft
    - Corrosion
    - Deterioration
    - Keeping track of material
    - Re-handling of materials
    - Storage of materials
    - Lost of Materials
    - Theft
    - Damaging

Technology

- Do you use a computer in your company for material ordering, material tracking?
- How effective is the computer system used for materials ordering, tracking?
- Recently several electronic devices have been developed for materials tracking and inventory control. Among these devices bar codes are included. Do you use any technology for inventory control on site?
- What are the problems associated with technologies used for materials management?
    - Damage of bar codes
- Do you use JIT delivery?
- Typical problems associated with JIT
    - Late deliveries
    - Wrong quantities delivered
    - Wrong materials delivered

	Problem	Description
Material takeoff and identification	Not a good scope definition	Not a good definition of what is wanted
	Lack of communication	Lack of communication between parties involved
	Incomplete Drawings	Plans are not complete and details are missing
	Lack of conformance to requirements	What is wanted by the customer is not what is prepared
	Nonstandard specifications	Use of specifications different from those commonly used
	Incomplete/ineffective meetings	Issues are not resolved in meetings
	Use of nonstandard items	Special Items that might require more time to be built
	Vague stated requirements	Don't communicate exactly what is wanted to suppliers
	Ambiguities between plans and specifications	Differences in requirements between plans and specifications
	Not determining when and what materials are needed	
Vendor Selection	Uncontrolled bid lists	Have too many suppliers bidding and don't have much information about them
	Incomplete proposals	Suppliers didn't include all documents required with the proposal
	Time spent investigating non-qualified suppliers	
Materials Procurement	Availability of material	The requested material is in inventory and the quantities required are available
	Availability of quantities required	
	Matching price to competitor's price	Customer asks for price reduction to match your competitor's price
	Late Deliveries	Materials are not delivered as scheduled
	Late or incorrect of submittals	Submittals are not submitted and approved as planned or incorrect ones are submitted
	Late approval of submittals	
	Poor communication	Lack of communication between parties involved
	Lack of conformance to requirements	What is wanted by the customer is not what is prepared
	Unrealistic delivery dates	Delivery dates are set that are impossible to meet
	Vague stated requirements	Don't communicate exactly what is wanted to suppliers
	Re-handling of materials	Materials have to be moved from one place to another before being installed
	Storage of materials	Storage areas are limited or are far from working area
	Lost of Materials	
	Theft	
	Damaging	Materials damaged while handling or by other conditions

Construction Phase	Late deliveries	Materials do not arrived as scheduled
	Incorrect type of materials delivered	There are differences in the materials ordered and the materials delivered
	Incorrect sizes delivered	
	Incorrect quantities delivered	
	Keeping track of material	Don’t know where materials are at certain period of time
	Re-handling of materials	Materials have to be moved from one place to another before being installed
	Storage of materials	Storage areas are limited or are far from working area
	Lost of Materials	
	Theft	
	Damaging	Materials damaged while handling or by other conditions
	No supplier QA	No quality assurance from the supplier
	Poor communication	Lack of communication between parties involved
	Receiving, handling and storage of unused materials	
Post-construction Phase	Can surplus be returned for credit?	
	Conditions and interests on outstanding bills	
	Return charges	
	Salvage losses	

Table A1: Problem Identification Questionnaire

Design	Description
Not a good definition of what is wanted	Not a good scope definition
Poor communication	Lack of communication between parties involved
Lack of conformance to requirements	What is wanted by the customer is not what is prepared
Nonstandard specifications	Use of specifications different from those commonly used
Incomplete/ineffective meetings	Issues are not resolved in meetings
Use of nonstandard items	Special Items that might require more time to be built
Uncontrolled bid lists	Have too many suppliers bidding and don't have much information about them
Vague stated requirements	Don't communicate exactly what is wanted to suppliers

Construction

Late deliveries	Materials do not arrive as scheduled
Incorrect type of materials delivered	There are differences in the materials ordered and the materials delivered
Incorrect sizes delivered	
Incorrect quantities delivered	
Keeping track of material	Don't know where materials are at certain period of time
Re-handling of materials	Materials have to be moved from one place to another before being installed
Storage of materials	Storage areas are limited or are far from working area
Lost of Materials	
Theft	
Damaging	Materials damaged while handling or by other conditions
No supplier QA	No quality assurance from the supplier
Poor communication	Lack of communication between parties involved

Supplier

Availability of material	The requested material is in inventory and the quantities required are available
Quantities required	
Matching price to competitor's price	Customer asks for price reduction to match your competitor's price
Late Delivery	Materials are not delivered are scheduled
Late or incorrect of submittals	Submittals are not submitted and approved as planned or incorrect ones are submitted
Late approval of submittals	
Poor communication	Lack of communication between parties involved
Lack of conformance to requirements	What is wanted by the customer is not what is prepared
Unrealistic delivery dates	Delivery dates are set that are impossible to meet

Table A2: Checklist for Problematic Issues

Appendix B: Flowcharts and Narratives

Appendix B presents the flowcharts for the material management process for the companies interviewed and the narratives for the flowcharts.

Majority of the interviews were conducted at the main offices of the companies. However, the interviews were complemented with site visits to different jobsites, warehouse/pre-fabrication shops and also interviews with the field/warehouse personnel.

All the interviews were recorded on tape. The information presented in this appendix only covers the aspects necessary to develop the flowcharts and subsequent narratives. Any other information needed, which might not be available in the appendix, was gathered by listening to the tapes. Is it not possible to publish all the information available in the tapes in this appendix, therefore only the information used in the development of the flowcharts and the flowcharts themselves are published.

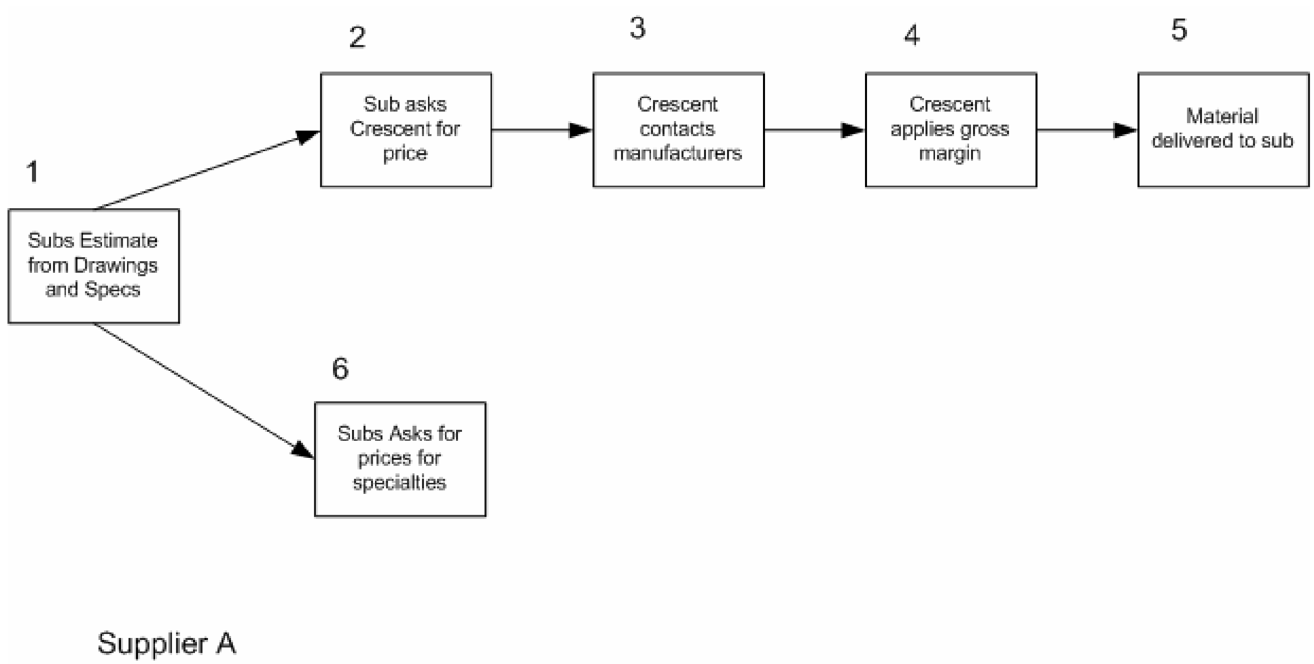

Figure B1: Flowchart Supplier A

Supplier A
Narrative

Straight Bid- Majority of Projects

Negotiated Project

Time and material project

1.0

- Depending on the size of project subs limit the number of distributors
- Sub takes off job and gives a list of materials to different distributors to get prices. They ask mostly for prices on distribution equipment (switch gears, safety switches, panels) and lighting. They send copies of the project schedule with expected installation dates for distribution equipment and for lightning.
- If the sub calls the manufacturer first, the distributor still gets involved, since the material has to go through the distributor

2, 3, 4, 5

- Supplier A limits their business to 1-2 manufacturers for partnering purposes and to get better prices
- Supplier A contacts manufacturers, gets prices and adds a profit margin
- Subs select the distributor based on lowest price (95% of times)
- For small panels Supplier A will assemble them, for big projects the manufacturer will assemble them

6.0

- Sub asks for prices on specialty type items such as cable tray and under floor ducts sometimes

Company is active in marketing themselves with contractors. Sometimes company gets contacted by people that used to work for some other company that dealt with Supplier A and moved to a new company.

Supplier A

Value Added Services

1.) Trailer on Site- First project this year

Supplier A buys a trailer and provides it with material ordered by the contractor in it. The contractor buys all the material in the truck. The contractor administers the truck once it goes to the jobsite. Once the job finishes, he returns the remaining material and Supplier A credits the contractor.

Supplier A could provide inventory management on the trailers. Salesman will go once a week to the trailer and verify materials needed and send them to the trailer.

2.) Manager material inventory on industrial sites- Salesman goes to the industrial site, verifies materials needed and send them to the site

3.) Yearly contracts

Supplier A doesn't offer yearly contracts on fixed price for commodities. They offer a yearly contract in which their profit is fixed. The item will be sold at the cost in that particular day plus the profit specified in the yearly contract. These contracts provide market share for Supplier A. Yearly contracts are not used for major items such as switch gears, fixtures. Supplier A can't fix the price of commodities such as wires and PVC piping, because their price is dependent on market conditions.

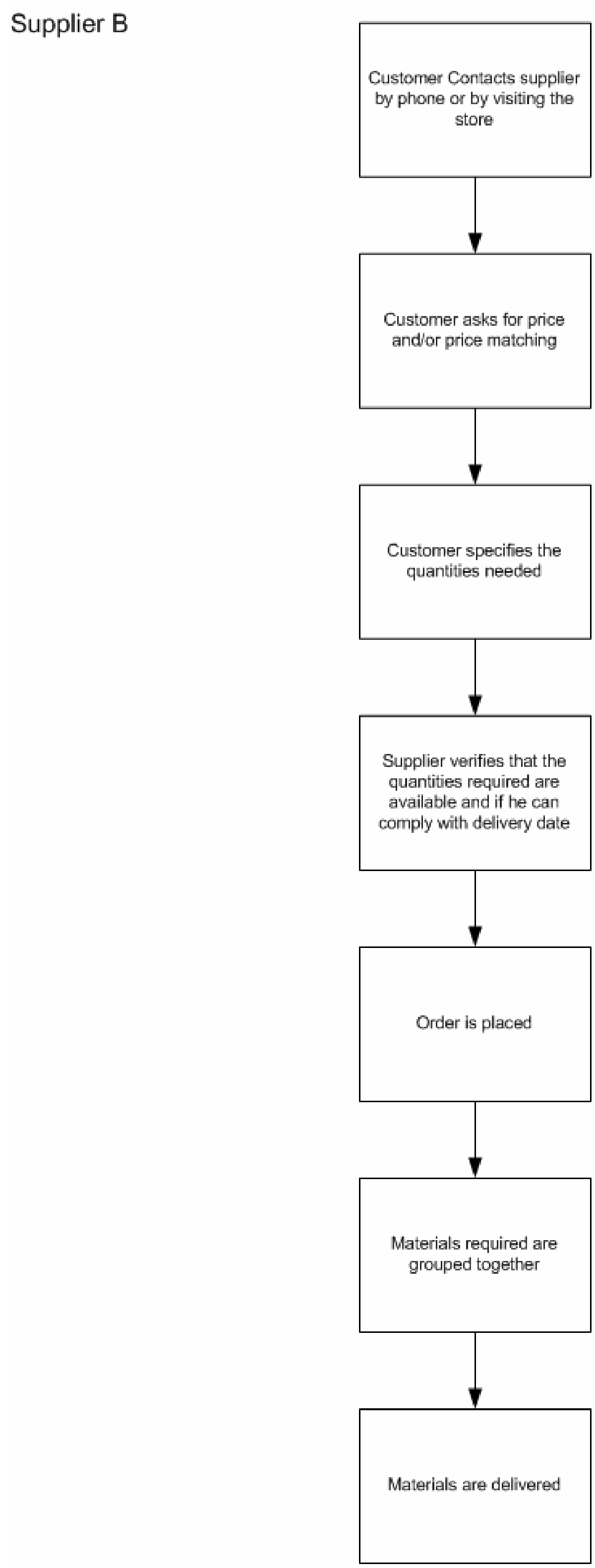

Figure B2: Flowchart Supplier B

Supplier B

Interview

1. What is the process that takes place when someone places an order until he receives it?

The process is fairly the same although it can be started by two different ways, either the customer gives us a phone call or he comes to the store. The customers ask for price, most of the times for matching price to other competitors, I give them the price and they tell me if they want it or not. The customer specifies the quantities needed, time and place of delivery. I verify if I have the quantities needed and the price that the customer wants it. I verify the delivery log to see if I will be able to deliver the material when is needed. The rest of the process is computer work.

2. What happens if you don't have the quantities that the customer needs?

If we don't have the quantities that the customer wants available at the moment, we can get the materials either from another Supplier B or from another supplier in the area.

3. Who monitors that process?

I personally monitor the process and make sure that the order is ready when the customer needs it. I can verify the status of the order in the computer and make sure everything is working the way it should be working.

4. Do you use any computer software for monitoring the process?

Computers are used to get the order ready, verify if the quantities are available and to bill quotes to customers.

5. Does the store delivers or customers have to pick up?

Most of the times the products have to be delivered. Depending on the time that the contractor needs the materials and load of work. Sometimes the customer comes and pick up the materials if they need them that same day.

6. How effective is the delivery? In terms of time and quality

Most of the times we deliver the materials at the specific day that we tell the customers, however this depends on the weather conditions, job site location and ease to get into the job site.

7. Do you do JIT delivery?

We can't deliver at a specific time because it depends on the workload that we have, however we can tell the customer if it's going to be delivered during the morning or the afternoon and the day of the delivery.

8. Do you do packaging, i.e. contractor requests different materials and you put it in a pallet for him?

A lot of times we will do that if it's an item that we can put in a pallet. The materials have to be fairly packed to go into the truck anyway. If the customer calls and specifies the materials he wants and that he wants them in a pallet or in a package we can usually do that for the customer.

9. What are the major problems that you can identify in the system?

I can't talk to you about the internal problems that we have.

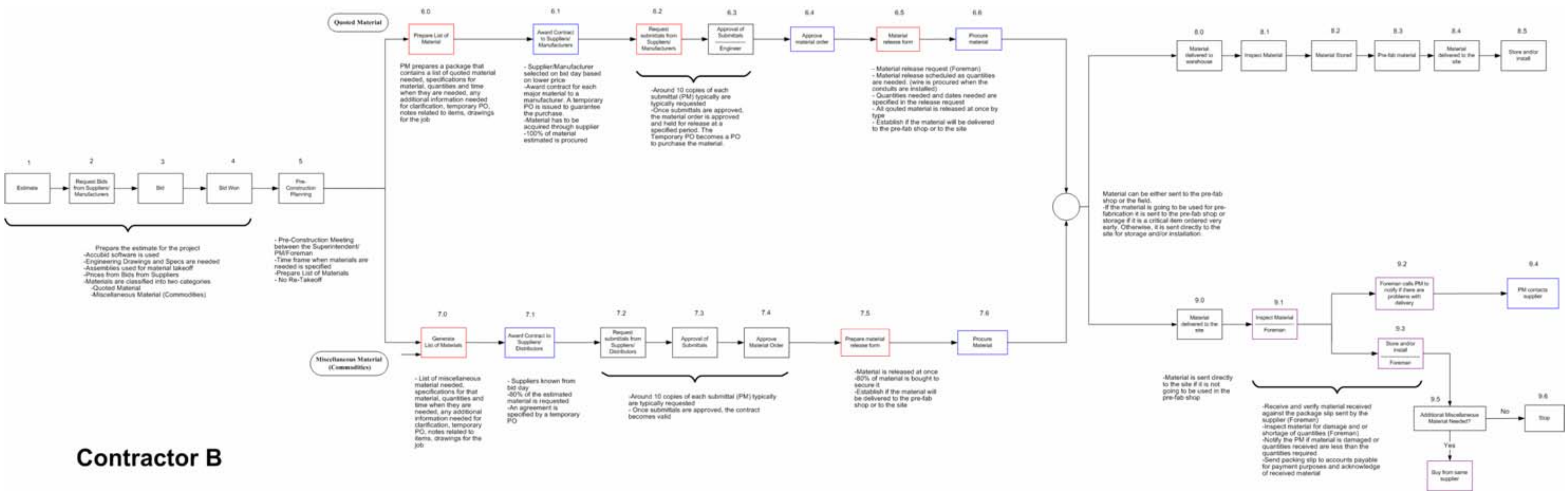

Figure B3: Flowchart Contractor B

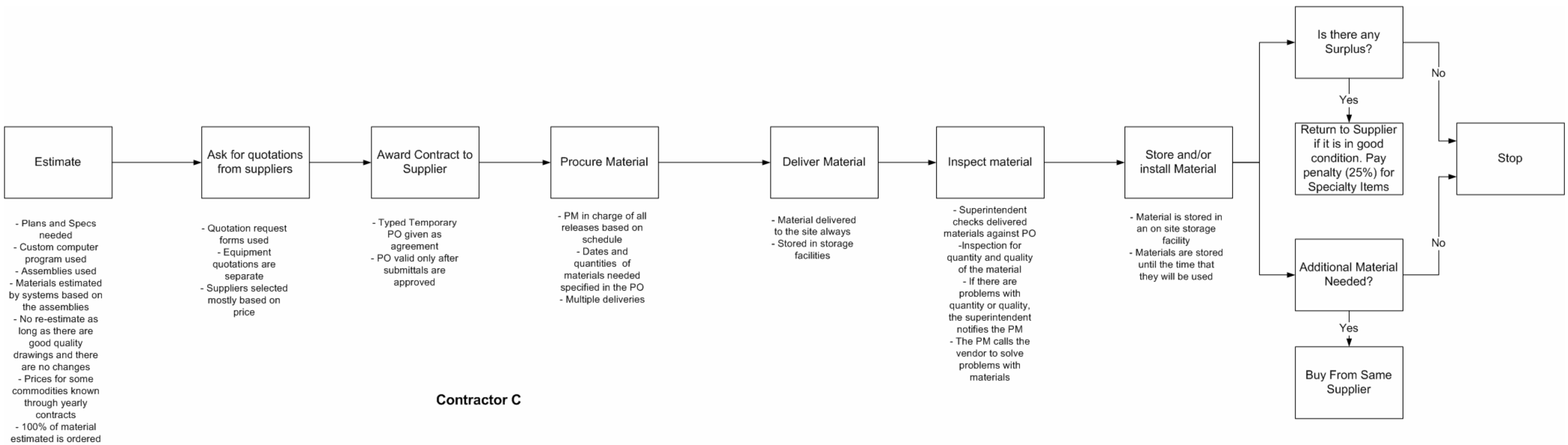

Figure B4: Flowchart Contractor C

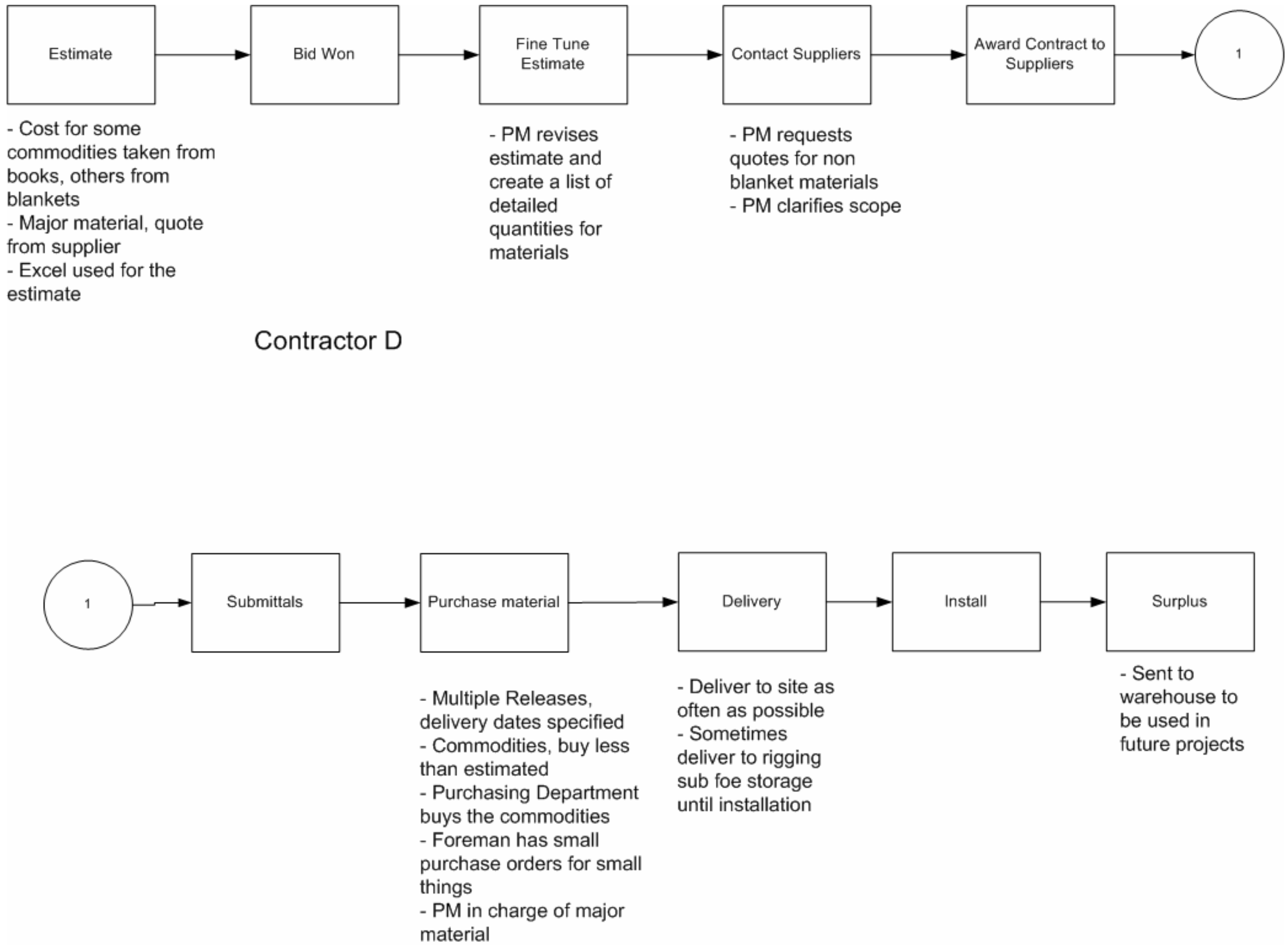

Figure B5: Flowchart Contractor D

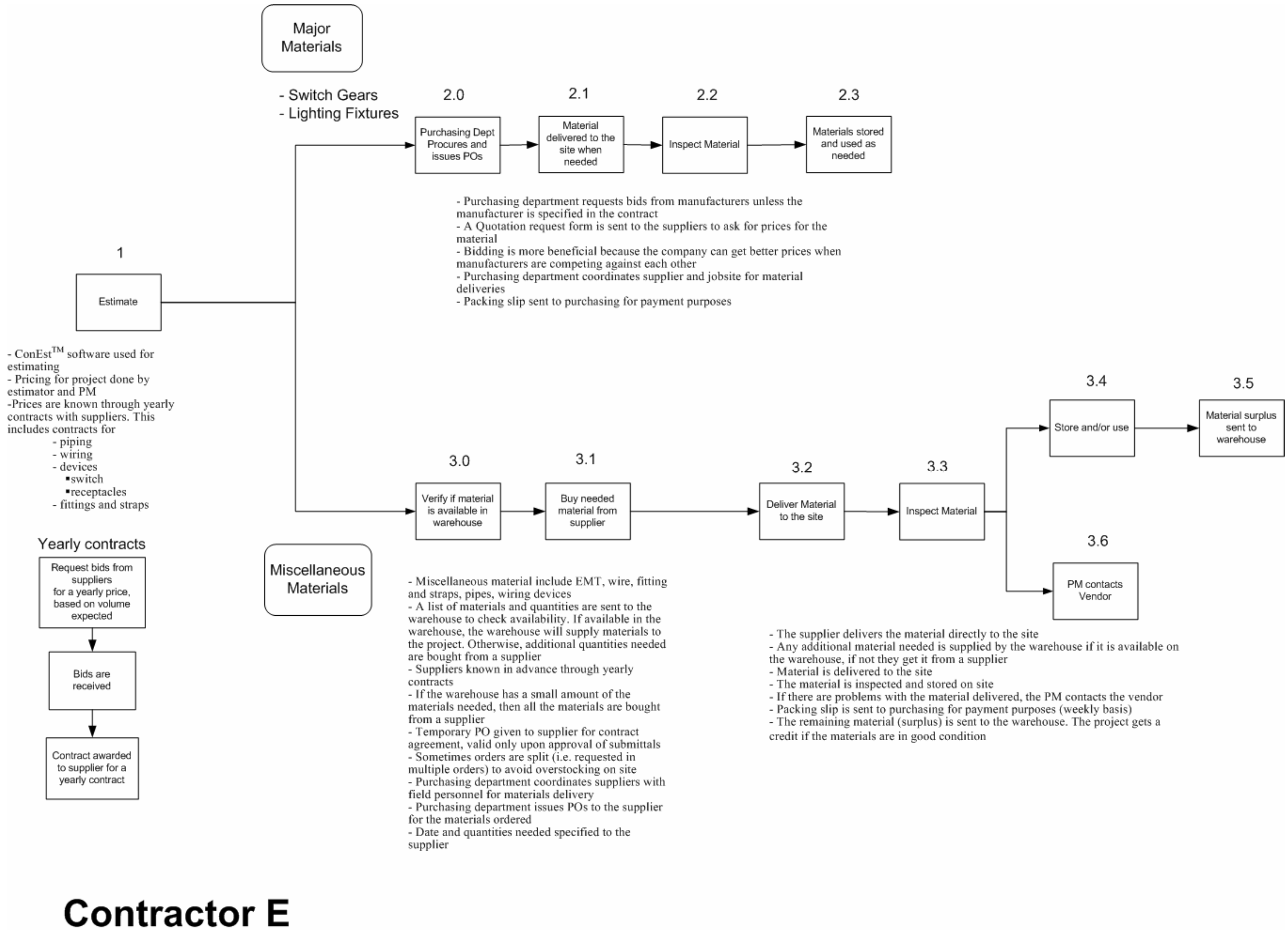

Figure B6: Flowchart Contractor E

Contractor E
Narrative

1.0

- Prices are known through yearly contracts with suppliers
    - piping
    - wiring
    - devices
        - switch
        - receptacles
    - fittings and straps

2.0, 2.1, 2.2

- Miscellaneous material include EMT, wire, fitting and straps, pipes, wiring devices
- A list of materials is sent to the warehouse to see if the materials are available
- If materials are available in the warehouse, the warehouse will supply materials to the project
- If the warehouse has a major part of the materials needed, they supply that amount of materials and the rest of bought from a supplier
- If the warehouse has a small amount of the materials needed, then all the materials are bought from a supplier
- Sometimes orders are split to avoid overstocking on the construction site
- Purchasing department coordinates suppliers with the site for materials delivery
- Purchasing department issues POs to the supplier for the materials ordered

2.3, 2.4, 2.5

- The supplier delivers the material directly to the site
- Any additional material needed is supplied by the warehouse if it is available on the warehouse, if not get it from supplier
- Material is delivered to the site and stored on site
- Packing slip is sent to purchasing for payment purposes

- The remaining material (surplus) is sent to the warehouse. The project gets a credit if the materials are in good condition

3.0

- Main materials are switch gears and lighting fixtures
- Purchasing department requests bids from manufacturers unless the manufacturer is specified in the contract
- Bidding is more beneficial because the company can get better prices when manufacturers are competing against each other
- Purchasing department coordinates supplier and jobsite for material deliveries
- Material delivered to site and used as needed

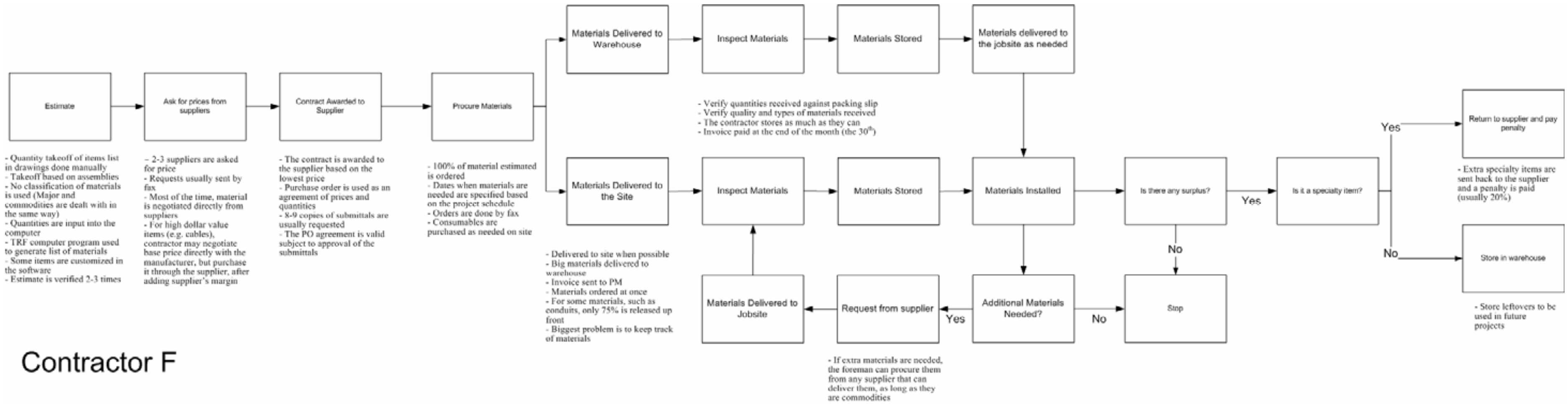

Figure B7: Flowchart Contractor F

Contractor F
Narrative

Estimate

- Quantity takeoff of items list in drawings done manually
- Takeoff based on assemblies
- No classification of materials used
- Quantities are input into the computer
- TRF computer program used to generate list of materials
- Some items are customized in the software
- Estimate is verified 2-3 times

Price Request

- 2-3 suppliers are asked for price
- Requests sent by fax mostly
- Most of the times the contractor deals wit the supplier
- In small occasions the contractor deals directly with manufacturer for high dollar value items such as cables

Contract Awarded to supplier

- If the contractor is the lowest bidder, the contract is awarded to the supplier based on the lowest price
- Purchase order is used as an agreement of prices and quantities
- The supplier submits submittal (8-9 copies)
- The agreement is valid upon approval of the submittals

Procure Materials

- 100% of material estimated is ordered
- Dates when materials are needed are specified based on the project schedule
- Orders are done by fax
- Foreman can buy commodities as they are needed on site

Materials Delivered

- Delivered to site when possible
- Big materials delivered to warehouse
- Invoice sent to PM
- Materials ordered at once
- For some materials, such as conduits, only 75% is released up front
- Biggest problem is to keep track of materials

Verify Materials

- Verify quantities received against packing slip
- Verify quality and types of materials received
- The contractor stores as much as they can
- Invoice paid at the end of the month (the 30th)

Material Surpluses

- Store leftovers to be used in future projects
- Specialty items, not of the shelf items, leftover are sent back to the supplier and a penalty is paid (usually 20%)
- Shelf items carry no guarantee if they are returned

Extra Materials Needed

- If extra materials are needed, the foreman can procure them from any supplier that can deliver them, as long as they are commodities

Pre-fab shop in place, but has not been used for a particular project yet

No yearly contracts are used, because the company can get better prices from different suppliers if they don't lock their selves for one year with a particular supplier

Contractor F

Second Interview

1. How do you decide amount of material to buy?

Material is normally ordered based on lead time. For example, major material requires normally more than 90 days for delivery. We buy the amount of material that was estimated since we verify our estimates 3-4 times.

2. Do you usually create delivery schedules in batches?

For miscellaneous material, we usually buy the entire package needed and store it in the jobsite.

3. Why buy the entire package and not schedule batches?

By buying the entire package we avoid prices increases. By giving the supplier a PO, this certifies that we will get the material at the quoted price.

4. The entire package needed is stored until it will be used. Do you consider inventory cost versus ordering in batches?

Material is sent to the site because you have to prove that the material is available before you can start building. We don't consider any storage cost. We are more worried for availability and delays in the project. In addition, we order material early because once the labor force is in the jobsite, it would be very costly for the company if there is no material for them to work.

5. How do you measure accuracy of the amount being ordered?

Usually our estimates are revised 3-4 times before we submit them. Once we get the job, we order the amount that was estimated and we include contingencies. As the work progresses, we verify the amount of inventory versus the amount of work remaining, if we have shortages we get the material from the same supplier.

6. How do you deal with theft, loss and misplacements?

Every foreman in the construction site verifies the inventory and keeps track of the material being used.

7. How do you decide what brand to buy and from whom?

Our suppliers are usually selected on lowest prices, we don't have blanket orders. If the brand is specified in the contract, we request quotes from the suppliers that can deliver that brand. Many times we have more than 2 suppliers in a job, because of the brand requirements.

8. If you could get the material in batches delivered just before you need them, would you do that?

We are more worried about delays and labor cost than inventory cost. We are not sure that the supplier will 100% deliver the material, therefore we prefer to store and have it available. If material is not available it can impact the labor cost, which can get very expensive.

9. Where do you store on site? Are there any contingencies for re-handling?

We normally store material in trailers. If there is space on the building floor, we store it there. If there are space constraints on the floor, we store in trucks and move it to the site as needed. We don't like to get into re-handling material on the building floor, it is time consuming and can be expensive. In addition, the owner will pay for stored material, so we prefer to minimize our risk of not having the material.

10. Mainly, from what I can get from this interview, you buy the total materials early, you deliver to the jobsite, you store it and you buy the amount of materials estimated. Is availability the most important factor?

Yes, as I said for us availability is more important that inventory cost as the owner will pay for stored material. The cost of purchasing is known from the estimate, so it is not unknown and no increases will happen. The inventory cost incurred now is smaller than the cost that will incur on labor and delays if the material is not available.

11. If there is a tool available that would allow you to analyze the tradeoffs between costs, availability, delays, etc. would you be willing to implement it?

If the tool can help me and we could cost savings without sacrificing availability on site I would consider it.

12. The main idea of this research is to develop a blueprint for a DSS for material supply chain, after our discussions and after seeing what we are considering, are you willing to give it a shot in your company?

I think that the research that you are conducting is very comprehensive and you are considering all the aspects that we should consider, but sometimes we don't. After talking to you a couple of times and knowing the scope of your research, I would definitely like to take a look at the final product. Lots of good ideas and suggestions might come out of it.

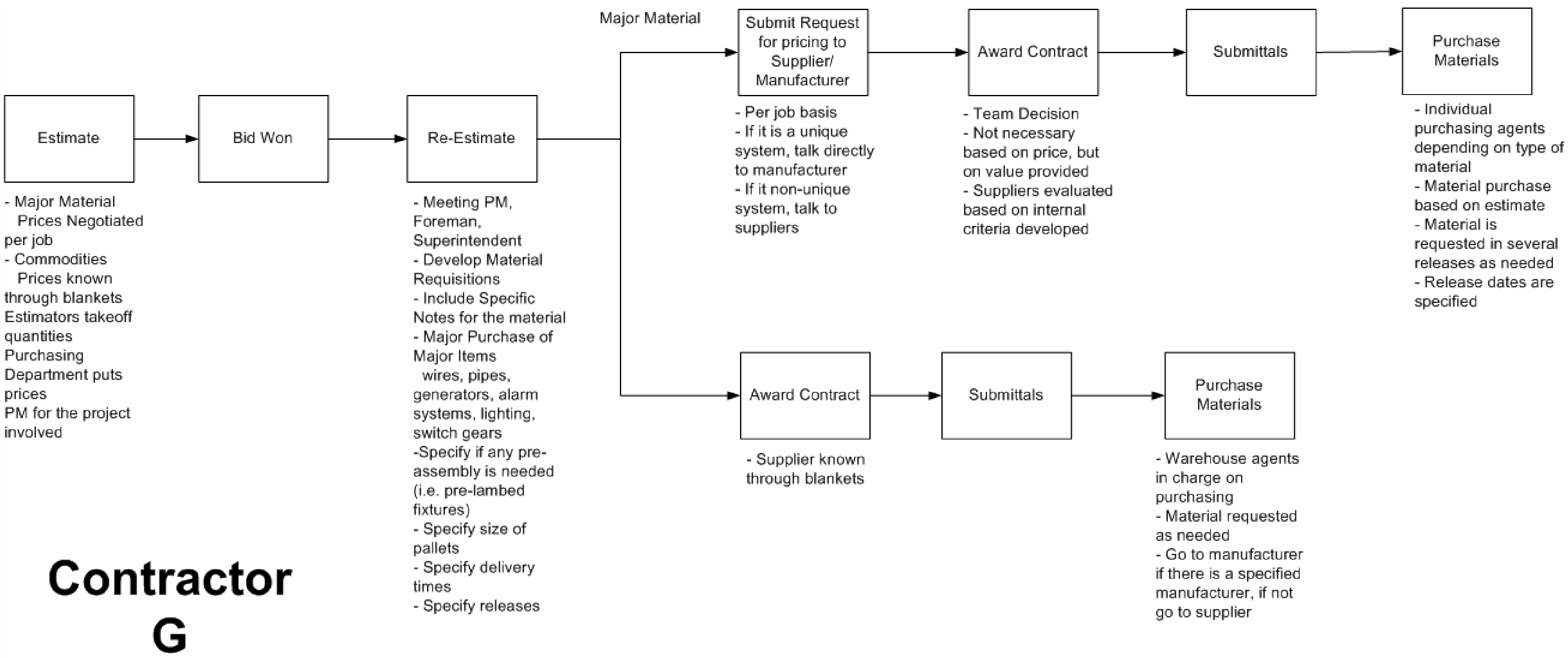

Figure B8: Flowchart Contractor G

Contractor H
First Interview- Purchasing Manager

General

- Do you have a classification for materials? Can you provide examples?
  - We mostly buy medium and low voltage products as we don't do any power work at the moment. Some materials, such as wiring, are bought in bulk. We don't classify the materials by category just by name.
- What are the major problems that you can identify in the system overall? What is the major problem that you fill has to be fixed? Can you elaborate on major issues?
  - The major problems are with materials that are already ordered and then there is a change in the project. These materials are paid for and can't be returned because the supplier will not accept them. Is not the supplier's fault, this situation arises because of changes requested by the owner or his representative.

How to order material

- What are the types of material that you usually buy from suppliers?
  - I buy all my materials from suppliers. As I said wiring in bulk and low to medium voltage products.
- How do you typically place an order? Give examples? Is the process different for different type of materials?
  - I use the internet, email and fax to place orders. Sometimes I call the supplier if I need the material if the process needs to be accelerated.
- Problems associated with the ordering process?
  - There are no major problems with the ordering process, most of the errors are human errors that can be fixed easily. Sometimes there are problems with materials that are not available, but those are isolated incidents.
- Do you typically pick your materials or you like the supplier to deliver them? Which type of materials you must likely pick up? Which type of materials would you prefer be delivered to you?

    - I would prefer the supplier to deliver as much material as they can. Sometimes if the material is needed in a rush we'll pick it up. We always want the supplier to deliver bulk material, because this material typically goes to the jobsite.
- Who follows up the order and makes sure that the materials will be on site when needed?
    - I personally ensure that the materials are received when expected in the construction site. Sometimes there are delays with material coming directly from the manufacturer, but that doesn't happen often.

How to qualify suppliers

- What are the procedures used to evaluate potential suppliers?
    - I've been working with same 7-8 suppliers for the last 20 years. The experience of work from previous jobs is very important for me. Depending on the materials and price offerings we decide from which supplier we are going to get the materials. Sometimes the specifications specify from which manufacturer they want the product, therefore this influences from which supplier we buy.
- What are the typical problems associated with the qualification process?
    - I don't qualify suppliers, because I do business with the same 7-8 suppliers.

Quality Issues

- Quality is specified in the specifications for a particular project. In order for approval of the work, the contractor has to meet the quality requirements specified. How are quality issues specified to the supplier?
    - Quality is specified to the supplier by the brand that we request. The quality is dictated by the manufacturer
- Sometimes when materials arrive to the site, they are not exactly what you order or don't meet the requirements specified. What are the typical problems associated with quality issues?

  - No major problems associated with quality issues. Just one time one manufacturer sent defective material, but the situation was corrected as soon as we noticed and talked to them.
- The contractor has to tell the supplier the quality expected and the tolerances for the materials. How are inspection procedures specified to the suppliers? Are the inspection procedures different for different type of materials?
  - The manufacturer dictates quality, therefore we buy materials based on manufacturer and the quality comes with the brand. Our superintendents verify that the materials have the quality specified.
- Typical problems associated with inspection procedures
  - No problems with inspection procedures until now
- Typical problems associated with received materials from suppliers? Can you provide examples?
  - No major problems associated with quality and suppliers. If there are problems, those problems will be with the manufacturer, not with the supplier.

Storage

- Do you keep inventory on site? If you do keep inventory, which materials are the most likely in your on site inventory? Which materials will never be in your inventory on site?
  - We store small things in the warehouse, like 1 day things (consumables) that we need. We receive material in site in large quantities as we needed on the jobsite. It functions like a just in time system, but we storage the quantities that we don't use in a particular day.
- How adequate are procedures for storage material on site?
  - The procedures to store material on site are good because we know which materials to store and where.
- Different things can happen to materials once it is stored on site due to weather, human factors, etc. What are the typical problems that you can associate with stored material?

    - We haven't experienced any major problems with stored materials on site. With our experience we know which materials we can store on site and which ones we can't.

Technology

- Do you use a computer in your company for material ordering, material tracking?
    - I use the computer for material ordering
- How effective is the computer system used for materials ordering, tracking?
    - The computer is very good to place orders
- Recently several electronic devices have been developed for materials tracking and inventory control. Among these devices bar codes are included. Do you use any technology for inventory control on site?
    - We don't use yet any bar codes or any other technology for materials tracking.
- What are the problems associated with technologies used for materials management?
    - N/A
- Do you use JIT delivery?
    - I prefer to have a buffer just in case that the material doesn't arrive on time
- Typical problems associated with JIT
    - N/A

Contractor H
Second Interview- Vice-President, Electrical Division

1. How do you decide on how much to order?

Usually 80% of the material needed is ordered. The ordering time is based on project schedule and the lead time specified by the supplier. Damage, loss, misplacements are not considered when ordering material, at the end we have to assume the costs associated with these.

2. How often do you order material and who decides on the batch amounts?

Get all the material for the job to be performed at once and store it until it is needed, in that way we can get discounts from the suppliers. In addition, we minimize the ordering costs per item.

3. Do you consider the tradeoff between inventory cost and availability?

We prefer to pay for storage instead of having delays. The cost of availability and possible delays versus storage costs has not being studied. We include a storage cost for material in our estimates.

4. If you have these numbers, would you change your ordering policy?

   Yes, if we could have numbers for material storage cost we could change our policy. However it also depends on the performance of the supplier.

5. How do you verify that the ordered quantities are correct?

The accuracy of the how much material is needed is realized when the job is progressing. At some point in the construction, the project manager verifies the work to be done and the material required and compares with the material available that is remaining, from the 80% ordered initially. If more material is needed, then it is ordered. The 80% is used to avoid surpluses that could result in re-stocking fees or inventory costs by storing in warehouse.

6. What are the major factors used to decide when to buy?

We order material two weeks in advance, based on lead time of the supplier. We store the material for availability purposes in case that there is schedule acceleration.

7. Suppose that the supplier could do a one day before needed delivery, would you be willing to deliver the day before needed?

If the supplier could deliver day before the material will be used, we would ask for delivery the day before usage. However, it is very difficult to ensure it. That’s why we order the material early and store it on site.

8. Do you have any problems with backorders?

We don’t have problems with backorders.

9. Where do you deliver your material?

All the material is requested to be delivered to the jobsite. It is usually stored in trailers.

10. Do you order material to store or material to install?

Usually all the material ordered is material to install. We store it on the jobsite, but not for long periods of time.

11. If you have a safety stock, would your ordering policies with respect to time and quantities change?

Yes, we would probably use the amount in stock first and then order the rest needed with a shorter ordering timing instead of the regular 2 weeks.

12. How do you track materials once they are delivered?

Materials are track with PO numbers and job numbers. We verify every shipment to the jobsite.

13. How do you tackle theft and loss of material?

We really don’t track amounts for that in a jobsite.

14. How do you decide on what brand to order and from whom?

Usually contracts specify more than one brand that can be used, so we request quotes from suppliers that distribute those brands. If we are pined to one brand, then we request quotes from suppliers that distribute that brand.

15. If a brand is specified and a blanket contract is in place, would you get the material from that particular supplier?

Not necessarily, blanket orders are supposed to give the lower price, but sometimes better prices can be obtained by bidding. We go with the better price.

16. How do you deal with material storage in the jobsite?

Sometimes the lay down areas are very small and we have to put our storage trucks far away from the jobsite. Sometimes, the location of the storage areas and cost associated with moving material to the building is not considered in the estimate.

17. Do you have any contingencies for material re-handling on the floor of the building?

No, re-handling costs are not considered in the estimate. It is difficult to assess and it would be difficult to get a job if all these contingencies are included in the estimate. The available space is specified by the GC.

18. How do you define the criticality of an item?

Most of the times the criticality is defined by the schedule and by the lead time of the material. A critical material is an item that if it is not available, delays the progress of the work or a material that is required by the GC by a certain date.

VITA

Jose Luis Perdomo-Rivera was born in Mayagüez, Puerto Rico on August 15, 1972. He is the youngest son of Maria J. Rivera and Luis Perdomo. He has an Associate Degree in Civil Engineering Technology, Construction Management, from the University of Puerto Rico- Ponce Campus, a Bachelor of Science degree in Civil Engineering from the University of Puerto Rico- Mayagüez Campus. Upon graduation, he went to work for a heavy/highway contractor as a field engineer and as a project administrator. He entered the graduate school at Virginia Polytechnic Institute and State University where he obtained a Master of Science degree in Civil and Environmental Engineering, Construction Engineering and Management, under the guidance of Dr. Julio Martinez. After finishing his Master of Science degree, he joined the Department of Building Construction at Virginia Tech to pursue a doctoral degree in Environmental Design and Planning, Building Construction and Management option, under the guidance of Dr. Walid Thabet. He will join the Department of Civil Engineering and Surveying at the University of Puerto Rico- Mayagüez Campus to teach and conduct research in the Construction Engineering and Management area. He is married to Arliz Lizardo. They are the proud parents of three beautiful kids, Gaby, Amanda and Cristian.