The Report committee for Ian Christopher McFarland

Certifies that this is the approved version of the following report:

Demand Forecasting for Job Order Products in Highly Technological and Emerging Industries

APPROVED BY

SUPERVISING COMMITTEE:

Supervisor:______________________________
Erhan Kutanoglu

____
Alan Gotcher

Demand Forecasting for Job Order Products in Highly Technological and Emerging Industries

by

Ian Christopher McFarland, B.A.; B.S.M.E.

Report

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Dedication

I would like to dedicate this report to the following people who have been instrumental in their support over the last two years:

Kristin Mannino, my best friend and soon to be wife without whose help I would never have been able to make it through this process. Her love and support has helped me along every step of the way.

My parents, Chris and Marie McFarland, who have always pushed me to do my best and achieve as much as I could. They have always shown me a tremendous amount of love and support.

My departed grandfather, Charles McFarland, who was always proud to have another engineer in the family. I know how proud he would be today as I strive to work towards being the engineer that he always pushed me to be.

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Demand Forecasting for Job Order Products in Highly Technological and Emerging Industries

by

Ian Christopher McFarland, MSE
The University of Texas at Austin, 2012
SUPERVISOR: Erhan Kutanoglu

Demand forecasting is an important step of a company's supply chain management process, allowing companies to project their needs for different components that are used in the final product. This is even more important in emerging industries with job order (or project-based) products where historical demands do not exist and components may not be readily available or may involve a long lead time. Developing a demand forecasting model which accurately projects the needs of components for a company can decrease costs while decreasing overall lead times of final products. This demand forecast model takes into account projected component needs along with the likelihood of successfully winning a project bid. The model is extended to four different demand forecasting formulas incorporating different use of the winning probabilities. Historical results are then used to compare the methods and their advantages and disadvantages are discussed.

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Chapter 1: Introduction

One of the key factors for a company to succeed is determining the best way to forecast supply and demand. For some companies this may involve forecasting sales and comparing the results to purchased inventory, while for others it may involve minimizing their inventory holding costs based on known demand. The process can be different and complex for each company. However, one key aspect remains the same across all fields: minimize the cost to the company and minimize the lead time to the customer.

1.1 Motivation for Problem

My motivation for evaluating supply and demand forecasting problems comes from my background and experience, having been able to witness first-hand what types of issues can arise due to inventory and supply chain problems. Seeing videos on the Internet and documentaries on TV of how warehouse fulfillment centers like Amazon.com® work or how airlines manage not only route placements but also crew, equipment and maintenance requirements has always interested me. This is what brought me into the field of Operations Research and Industrial Engineering since the entire field is based on problem solving. Every company in the world, large and small, has some sort of logistics, supply chain, or cost problem to solve. These problems can stem from a manufacturing, financial, or logistical point of view but bottom line is that they are present in every industry. I view the field as a heavily applied field that can bring real, tangible results to a company. My initial first-hand experience with these types of situations occurred when I started as a Project Management Intern for the company that I currently work for, Xtreme Power® (XP), a provider of energy storage systems. I manage first-hand a variety of projects. This has given me a hands-on view of what must be used in order to get a project through every step of the process, from a project proposal to a customer to a commercially operational unit at a customer's facility. I have witnessed the strains that are placed on both the employees and the systems in place at a small to mid-size start-up company. Of particular concern are the hardships of ensuring equipment is delivered on time and to the standard of quality that is expected.

This experience is the motivation behind my research and my report. I see the need to find ways to minimize lead times through whatever means are available in order to create a more competitive and attractive product to the customer. Customers in the energy storage market range from small-scale regional companies to large-scale globally known conglomerates. Each has a different view, process, and expectation. However, each also has two attributes in common that can win or lose a project: cost and time. A customer may never find it conducive to purchase your product if the price is higher or if the lead time is greater than that of your competitors. If a customer does decide to purchase, they expect the quality of your product to surpass all others. Since the project marketing and proposal process takes a great deal of both time and effort, it is important to give yourself every advantage that you can in order to succeed. This serves as my motivation for my report: finding a means to determine and analyze the future potential of projects on the short to medium term horizon, typically between 3-18 months into the future. Certain long lead items common to each product can be procured in advance to help reduce the overall lead time of the delivery of the product. An accurate forecasting model will then in turn increase the competitiveness of your product in the market.

1.2 Sample Problem

A company is looking at three potential projects for quarter 1. Bids for each have been made and the company is awaiting word from the clients on the success or failure of their proposals. In anticipation of winning some combination of bids, the company is looking at purchasing some components in advance. Each project has two main components in common that have long lead times which could affect the delivery date of each project: power cells and inverters. The three projects are described as follows in Table 1.

	Probability of Project Bid Success	Demand in Quarter 1 of Power Cells	Demand in Quarter 1 of Inverters
Project A	75%	1000	1
Project B	50%	8000	4
Project C	25%	5000	5

Table 1: Description of Sample Problem

There are 8 different outcomes that could occur based on the success or failure of each individual bid. These outcomes are described as follows in Table 2.

Potential Outcome	**Power Cell Demand**	**Inverter Demand**	**Probability**
No project is won	0	0	0.09375
Won : A **Lost : B & C**	1000	1	0.28125
Won : B **Lost : A & C**	8000	4	0.09375
Won : C **Lost : A& B**	5000	5	0.03125
Won : A & B **Lost : C**	9000	5	0.28125
Won : A & C **Lost : B**	6000	6	0.09375
Won : B & C **Lost : A**	13000	9	0.03125
All projects are won	14000	10	0.09375

Table 2: Outcomes of Sample Problem

Procuring the power cells and inverters in advance for the exact quantity that will be needed is unlikely. Having too little inventory on hand may delay the delivery of one or more won projects, possibly resulting in liquidated damages needing to be paid to the customer. However having too much inventory could cost the company money and space for storage. Determining the best possible forecast for this situation will allow the company to make the optimal decision.

1.3 Company Background

1.3.1 Company and Product Background

The company that I will be using as the case study for my research is XP based in Kyle, Texas. XP is an energy storage solutions provider of battery storage systems for the energy industry. These storage systems provide a wide range of functions for energy farms, notably storing off-peak energy to be used during peak hours at wind or solar farms. The systems are also capable of helping to control ramp rates between energy providers and the electrical grid, aiding electrical capabilities of remote locations, and providing instantaneous back-up power in the event of a power failure. XP "designs, engineers, manufactures, and operates integrated energy storage and power management systems" that are customizable to a customer's needs. The standard system has a power capacity of 1.5 Megavolt-ampere (MVA), an energy storage rating of 1.0 Megawatt-hour (MWh), and a configurable control system designed to operate within a customer's assets and infrastructure (Xtreme Power). Each system is customized and designed in order to provide any level of power and energy storage ratings as is required by the customer. Due to the complexity of these systems there is a large amount of design, production, and procurement that goes into their manufacturing. The systems are complex, with long lead times involved for procurement of some components as well as for the design and manufacturing of the system in its entirety.

The type of product common in this industry is a job order type of product meaning that in general, it is made and produced for a specific customer request (called project). While different projects may have similarities, different energy or power requirements by the customer and different environmental conditions based on the customer's location force a job-specific order. Nearly all jobs begin with an energy company submitting a Request for Proposal (RFP). This RFP is received by the sales and business development departments of an energy storage company, such as XP, who then determines whether or not it is in the company's best interests to bid for the job. The business development team will determine whether or not the project meets management's strategic vision of the company. They will also determine the probability of successfully bidding (winning) the project. This process of developing a bid success probability will fluctuate on an individual company basis. If a company chooses to bid, it will submit a bid packet containing information such as system specifications, drawings, price, schedule, etc. which will then be reviewed by the buyer. The buyer will respond with any questions as will the bidding company to fine tune the proposal. One or more companies are eventually short-listed by the buyer for the job. A contract is negotiated between the buyer, the energy company, and the supplier, the energy storage provider, which upon being signed will create the customer demand being formally recognized by the winning company. Prior to a signed contract there is no guarantee of winning the job, thus customer demand can only be speculated until it is realized (under contract). A sample flow process for this type of bidding is shown in Illustration 1.

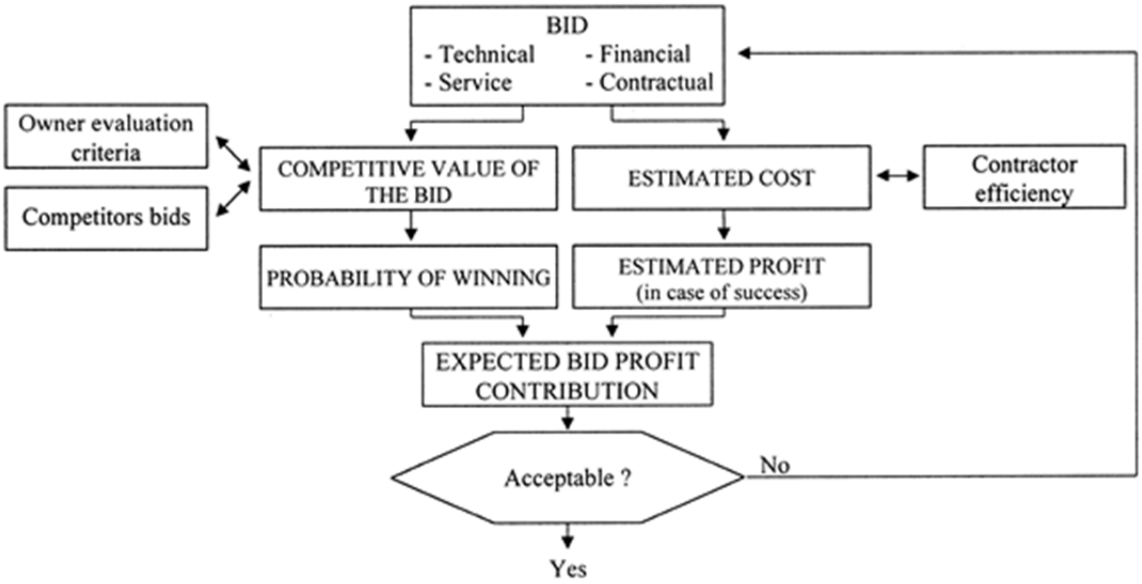

Illustration 1: Decision Framework in the Bid Preparation Process (Cagno, Caron, & Perego, 2001)

1.3.2 Project Process Background

Another aspect of projects at XP is the use of its supply chain in satisfying the customer's demand. There are four different types of supply chain designs (Feng, 2006):

(1) Make-to-Stock (MTS) – The company uses finished inventory to satisfy customer demand. The entire finished product is completed prior to the demand by the customer being realized. This requires an approved design of a product as well as the purchase of all needed components prior to any recognized demand. Under MTS, lead time experienced by the customer is minimal and customization is nearly non-existent.

(2) Assemble-to-Order (ATO) – The company assembles products from a finished inventory of components that exists prior to customer demand being

realized. Upon recognition of customer demand, the product is assembled from the finished components. This requires an approved design of a product as well as the purchase of all needed components prior to any recognized demand. Under ATO, lead time experienced by the customer is moderate and customization is limited.

(3) Make-to-Order (MTO) – Components are approved and modified based on customer requests once the demand is realized. The approved design of the product is set; however, simple modifications are made based on any customer requests. Under MTO, lead time experienced by the customer is long and customization is moderate.

(4) Engineer-to-Order (ETO) – Products and components, if needed, are designed from the beginning based on the customer's requests and specifications. Once a design is approved components are procured and assembly of the final product begins. Under ETO, lead time experienced by the customer is extremely long and customization is high.

These different supply chain systems can be compared in Table 3.

	MTS	ATO	MTO	ETO
Point of order entry	At point of stock	Prior to Assembly	Prior to Fabrication	Prior to Drawing
Pull point	Point of stock to upstream	Point of assembly upstream	Point of fabrication supply base	No pull
Inventory Speculation	End-item speculation	Module Speculation	Component Speculation	None
Lead time to customer	Minimal	Short	Long	Longest
Degrees of customer choice	Limited	Modularized	Semi-customized	Customized

Table 3: Comparison of Supply Chain Systems (Feng, 2006)

XP uses ETO for its energy storage system production. While this provides XP with the high customization that gives them an advantage in the industry, the same system creates a long lead time that results in a disadvantage. The entire energy storage industry is relatively new and constantly evolving, which results in longer lead times regardless of the company involved. However, a shortened product lead time would provide a strong advantage to XP giving them uniqueness in the industry.

1.4 Background to the problem

The main problem for XP is the long lead time that is associated with each customized and engineered-to-order product. The manufacturing process ensures that both the correctly rated equipment is built and the reliability of any equipment meets the customers' expectations. It, unfortunately, also results in long overall lead times for the delivery of the final product as some parts with long procurement lead times are not ordered until there is an order in hand. The ultimate goal is to maintain a system that continues to offer the customized product while shortening the overall lead time of the product to make them more competitive with companies that use MTS or ATO. These companies exists in the energy storage industry be producing a single product with low customization. The single product production allows for lower manufacturing costs which partially offsets the costs of incurred due to lack of customization. This is due to products needing to be overrated for power and energy rating since only one type of product is available.

1.4.1 Holding Inventory of Long Lead-Time Items

One common way to reduce lead time is to procure items with a long lead time in advance of having an order from a customer. While this allows the item to be readily available for a customer's order, these items are usually large and expensive. The main drawback to this scenario is that it is difficult for a small start-up company to commit funds to purchase expensive components for demand that has not yet been realized. The size of the components may be large physically so that the company cannot commit to the storage space required to place these components into inventory should they not be needed for several months. While having the long lead time components on hand would drastically reduce the overall customer lead time of the final product, the costs of storing the components for many months may not make it beneficial to keep them in inventory.

One way to reduce the overall lead time and ensure that a long lead time component is used in a timely manner is to forecast the demand of components that may be used for future sold products. In order to do this, projects that are currently in the bid or short-listed phase can be analyzed and the number of components that are needed in the future can be forecasted. For example, if you can determine with a high degree of certainty that you will need 5 units of component A during quarter 2 of 2012, then the company will be inclined to purchase the 5 units even though the customer demand has yet to be realized. This requires coordination between the marketing, sales, and operations divisions of the company in order to determine what can be produced as well as what project bids are expected to be successful. The bid success probability given to each outstanding project bid or proposal is also required. The bid success probability is based on industry, corporate, and historical data.

1.4.2 Project Marketing & Probability Analysis

One of the most important factors that can be determined for a project bid or proposal is the bid success probability for winning the project. As discussed before there is no guarantee that demand will be realized until a formal contract is signed with the customer. However, due to constraints relating to cost, schedule, liquidated damages, capacity, etc. it may be extremely beneficial to get as much of a head start on a project as possible, thereby reducing the lead time for ultimate delivery of the product to the customer. In order to do this the company assigns a bid success probability to each project. This will allow the company to place a higher priority on projects that are more likely to be won by the company. For example, if the company predicts a 10% chance of winning project A and an 80% chance of winning project B, they will place a much higher emphasis in preparing their resources for project B, rather than for project A.

1.5 Introduction to Research and Models

All data in this report has been collected by or provided to the author. The data is the proprietary information of XP and has been modified or disguised in order to protect XP, its customers, and the author. The changes made ensure that the data provides accurate results and conclusions made from this research.

The research and experiment set up in this report evaluates two different, yet critical, components needed for the final product for an energy storage system. These components are the power cells and inverters. The quantity demanded of each of the components for a project changes based on the power and energy ratings, as determined from the customer's requirements and specifications. The overall need for these two components is evaluated on a quarterly basis based on both known and projected demand. This requires two key factors for each project. First is the project schedule which is custom made based on the needs and requirement. Each project schedule reflects the demand for both the power cells and the inverters. Depending on the size of the project, the demand for these components may be restricted to only one quarter or could be spread over multiple quarters, as is often the case with large projects due to capacity constraints by the company and its suppliers. The second factor is the bid success probability for each project. This is an internally calculated number by the company which reflects the most accurate possible probability of the firm winning a specific project and needing to realize demand for that project. The details for this probability will be discussed later.

1.6 Benefits of Research and Models

The goal of this report is to provide research and models that support a system which has the ability to improve lead times and project prediction capabilities for companies that are job order based ETO systems. This concept is narrowed for the purposes of this report to small to mid-size companies in the energy storage industry. However, there is no reason why this same concept could not be transferred over into other industries which use similar methods of production, project management, and/or manufacturing systems. A successful implementation of this system will allow for ETO companies to maintain the advantages of ETO systems while eliminating some of the disadvantages of ETO, namely long lead times. A system is created with similar benefits as ATO systems which allow for a more cost effective operation and improved responsiveness to change and customization as requested by the customer (Aouam, 2010). The system will also provide a shorter overall lead time to a customer for delivery by examining if certain long lead components of the final product can be ordered in advance of demand realization based on the predicted bid success probabilities of outstanding project proposals and bids.

Chapter 2: Literature Review

While the specific topic of inventory systems for small, engineer-to-order companies has not been extensively studied, there are many studies on supply chain management, project marketing, and engineer/assemble-to-order systems. In order to better understand past work done on the related topics, the literature will be separated into marketing/business development and operations/manufacturing points of view. Each of these divisions contributes significantly different ideas and actions to a company. However, both are working towards the same goal: an efficient production system that maximizes the profit for the company.

2.1 Marketing

The marketing division of a company is in charge of selling, advertising and promoting the products, goods and services of the company. This includes seeking out any and all avenues and points of sale which may have demand for your product and creating a new demand in new markets. Networking with companies, clients, and partners in order to advertise and grow a product is essential to expand its market-share (Kerin, Hartley, & Rudelius, 2009). The marketing division of a company generally has objectives related to its financial aspects. Maximizing the revenue from sales, increasing the number of customers and/or orders, or achieving certain revenue or committed project value milestones are examples of these objectives. The main constraint against the marketing, sales, and business development departments is ensuring that demands are met.

Forecasting models from a marketing point of view can vary drastically depending on the outlook of the model. While each of the categories of models has its own benefits there is no formal demarcation between them. This means that some flexibility of customization is possible in order for a company to fit their specific market and needs (Lewis, 1997). Table 4 gives a general description, timeframe, and possible techniques for each of the different categories of models.

Outlook of forecast	Time period associated with the data being analyzed	Example of forecasting application	Forecasting technique used
Immediate-term	1/4 hr to 1 day	Electricity demand forecasting	Various
Short-term	1 week to 1 month	Demand forecasting in industry and commerce	Exponentially weighted averages and derivatives
Medium-term	1 month to 1 year	Sales and financial forecasting	Regression, curve fitting, time series analysis
Long-term	1 year to 1 decade	Technological forecasting	DELPHI, think tanks, etc.

Table 4: Forecasting Model Categories (Lewis, 1997)

For a small to medium size company with a unique, long lead product, such as XP, sales forecasting will mostly entail using a medium and long-term approach in order to predict potential sales, and market changes, as well as new potential markets for the future. This allows forecasting of sales and financial data for the next several quarters for the company. This information, while important for manufacturing and operations, is most beneficial to the marketing and business divisions of a firm. Most information is based on what the company projects their demand will be over a certain period of time. Researching customer demand, one finds that there are typically four different types of demand, as shown in Table 5.

1) Stationary Demand – This type of demand assumes that, although there are some fluctuations per unit time, the demand has no apparent long-term growth, seasonal trends, or randomness. It can be expected that some occasional small fluctuations in the demand can occur through either (1) impulses, individual demands that are higher or lower than normal, or (2) step growth, in which a series of successive demands are higher or lower. However, in general growth does not take place exponentially over the long term (Lewis, 1997).
2) Demand with growth characteristics – This type of demand exhibits a growth characteristic over a long term, either exponentially or linearly. Growth is continuous over the long term and does not return to its initial level. Growth can either be positive or negative (Lewis, 1997).
3) Demand with Seasonal Characteristics – This type of demand is one in which the demand typically follows a stationary demand pattern except for a certain period (or two) in which the demand is significantly higher or lower than all others. Demand then return to its regular level following this

seasonal irregularity. It is similar to what certain companies and industries experience during holidays or summer (Lewis, 1997).

4) Random or Unknown Demand – This type of demand is the hardest to predict as there is no pattern behind it. Demand in this scenario is random and probably unknown to the firm. While most firms generally have some expectation of what demand is, uncertainty or fluctuations make it a near random demand.

Type of Customer Demand	**Characteristics**	**Difficulty of Forecasting**
Stationary Demand	Slight fluctuation per unit time, no apparent long-term growth or seasonal trends	Little Difficulty
Demand with Growth Characteristics	Over a long period of time demand exhibits a growth characteristic, this growth may be positive or negative	Moderate Difficulty
Demand with Seasonal Characteristics	Demand remains near stationary except for one period which is influenced annually. Period is typically a month or quarter in which demand is higher or lower than all others	Moderate Difficulty
Random or Unknown Demand	Demand is random and is independent from one period to another.	High Difficulty

Table 5: Types of Customer Demand

A visual representation of each of these demand types over 24 periods is shown in Figure 1 highlighting the major differences that exist between them.

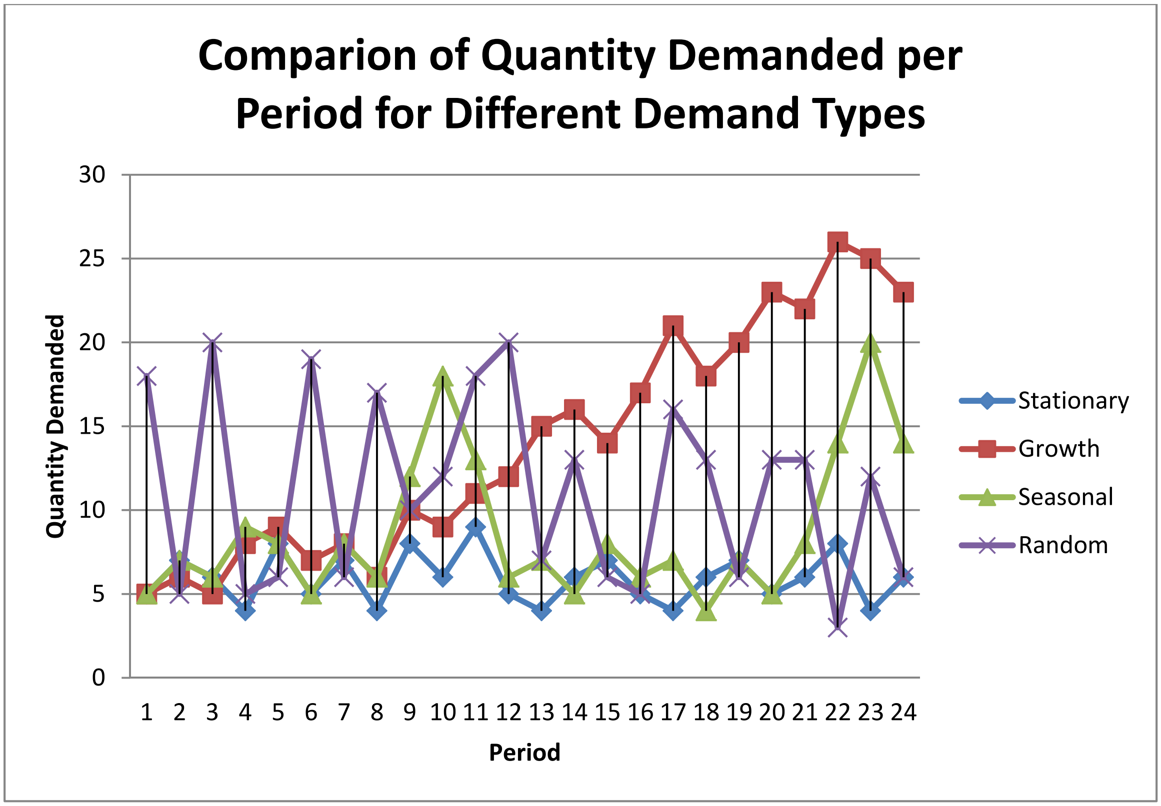

Figure 1: Comparison of Demand Types

While demand is one important aspect of marketing, another aspect specific to job order firms is project marketing and competitive bidding. Whereas most industries build to stock and sell an established product, ETO firms generally build product for a specific project that has been bid out to a customer and won. This is commonplace in the industrial and public markets for contracting and subcontracting work (Bansard, Cova, & Salle, 1993). Typically a customer, the buyer, defines their own requirements and needs then requests proposals from a variety of different companies on what they can provide. The customer then chooses between comparable proposals based on price and quality of the product (Bansard, Cova, & Salle, 1993). On the opposite side, the supplier uses their marketing and business teams to best position themselves for success with the proposal. While the process favors the buyer, the company must use price, networking, and negotiations in an attempt to level the playing field. A true project marketing strategy accounts for the capacities and strengths of the company, the management and decision making of the customer, and the abilities and methods of all competitors.

In this environment it is difficult to determine the exact type of demand forecasting and modeling to use. The small yet highly technological field of energy storage makes it more evident how critical forecasting becomes. An error in the forecast for a new or existing product at this stage can have “company-wide ramifications that can translate into significant bottom line consequences” (Kahn, 2002). Industry and academia have developed many marketing forecasting modules each of which has its own pros and cons. In general, however, each model has the goal of analyzing a new product entering a market or determining the future demand for a product currently in the market.

Models for products entering a new market are often designed to look at both the short and long-term viability of the product. They also analyze some combination of: impact of the marketing variable, competitor’s and trade’s reactions, and environmental conditions; all of which can affect the new product’s sales. It is also important to evaluate the impact of a new product on the viability and profitability of the firm and sales of its current products. These models gather this information by using management and expert opinions, similar product’s data, and consumer and market responses (Mahajan & Wind, 1988). Products that already exist in a market will undergo a slightly different method of forecasting and models, however the sources and goals described above hold a great similarity.

One straightforward method is a market-dominating coordination approach (MDCA) in which the marketing division of a firm determines a demand rate/production volume which is based on the marginal cost (MC) provided by the production side of the firm. The marketing division sends the manufacturing division this production rate and it is adjusted accordingly by the production side before returning to the marketing division. This iterative process continues until an “optimal” solution is found which can then be compared to the marginal revenue (MR). The MDCA approach converges to optimal whenever $|MC'| < |MR'|$ and diverges otherwise. Therefore if $|MC'| < |MR'|$ then the MDCA approach can be used (Kim & Lee, 1998). A similar method for a production-dominating coordination approach (PDCA) developed by the same authors provides optimality in the opposite situation in which $|MC'| > |MR'|$.

While there exists a multitude of approaches from a marketing standpoint on determining production rates, inventories, or demands, it is clear that the production and operations side needs to be viewed before a method that satisfies both can be determined.

2.2 Operations and Production

The operations and manufacturing side of a company is in charge of the procurement of raw materials, development and manufacturing of the final product, and maintaining the quality standards that are demanded. This means ensuring that raw material inventory levels and production capacity of the plant allow for a job to be completed on schedule. Failure to meet one of these two criteria can result in lost opportunity for the company which may not allow for the company to meet financial and product goals that were set forth, in part, by the marketing division as discussed in Section 2.1. In general, the operations side attempts to minimize their overall production cost and maximize the utilization of resources by efficiently using machines and personnel. The main constraints that hinder this are the limited supply of raw materials and resources, notably personnel and production capabilities.

In order to meet these objectives, the holding and ordering of inventory of raw materials is extremely important. The demands of the customer do not generally correspond to the supply of raw materials and other resources. While a customer with a small demand order will probably be able to effectively and efficiently order what is needed. However, a customer with a large demand order is more prone to being subjected to the constraints of the supplier (Lewis, 1997). This leads to one of the main benefits of holding a stock of raw or procured material on site that is needed for manufacturing processes. Another benefit is that replenishment orders for inventory are usually relatively large orders which can reduce the unit cost. This reduction is due to longer production runs absorbing fixed costs more effectively, discounts or price breaks for larger orders, as well as lower shipping and handling costs (Lewis, 1997).

While holding inventory has upsides there are also potential downsides that can offset the benefits. These have to do with the specific operating costs that are incurred with holding inventory on a site. A substantial, however not limited, list of these costs is as follows (Lewis, 1997):

1) Ordering Costs – Includes any paperwork, labor, etc. costs that are associated with placing the replenishment order.
2) Storage/Holding Costs – Generally viewed as a percentage of the cost of the unit that incorporates the costs of any money borrowed to procure the order, direct costs of storing the goods (wages, facilities, transport, equipment, etc.), costs of preventing deterioration of stock, costs of scrapping or reworking obsolete stock, and costs of any type of insurance covering stock. The sum of these costs is generally found to be between 20-30% of the cost of the item.
3) Stockout Costs – Costs incurred as a result of not being able to fulfill a customer's order due to non-sufficient stock.
4) Administration Costs – Costs to cover the fixed costs incurred due to stock.

The task of taking into account both the benefits and costs of ordering and holding of inventory items generally falls to the supply chain management of a company. A simplified example of a supply chain relationship is shown in Illustration 2 below:

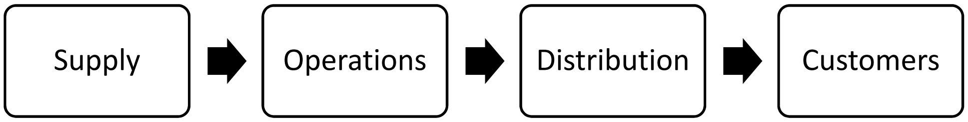

Illustration 2: Simplified Supply Chain (Kim, 2005)

The main goal of supply chain management is “to [create a] buffer against uncertainty” by holding an inventory of goods between when they are provided by the supplier and when they are used by production. (Kim B. , 2005). This is beneficial to the supplier as they are providing the company goods in a consistent, timely manner. Likewise, this allows the company to have a steady supply of raw material, which if needed can be placed into inventory for use whenever the demand may exceed supply. Without this inventory it may be necessary for the production facility to stop production until the next batch of material arrives from the supplier. However, it is also crucial for this to work not only on one level with a single component, but on multiple levels with multiple components needed for production. Coordination with other supply chain partners and companies is needed in order to ensure reliability. (Kim B. , 2005).

When managing a supply chain there are several methods that have been developed to determine the total cost, optimal order quantity, or inventory tracking system that can be used to optimize costs and benefits. One example is the Economic Order Quantity (EOQ) method which calculates the number of goods that should be ordered at a time as a function of holding cost, setup cost, and order cost. EOQ is based on the total cost formula (Hopp & Spearman, 2008):

$$Total\ Cost = \frac{hQ}{2} + \frac{AD}{Q} + cD \tag{1}$$

Which produces the well-known EOQ formula as follows (Hopp & Spearman, 2008):

$$EOQ = \sqrt{\frac{2AD}{ic}} \tag{2}$$

Average inventory investment reflects the investment that a company currently has committed to inventory (Hopp & Spearman, 2008):

$$I = \frac{cQ}{2} = \frac{cD}{2F} \tag{3}$$

Another popular method of determining order points and quantities is the Material Requirements Planning (MRP) system. This system, shown in Table 6 with an example, accounts for the known demand for any item and the lead times for any of its components, along with any sub-components if needed.

Part A		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Gross requirements		15	10	40	10	30	30	30	30
Scheduled receipts		10	10		100				
Adjusted SRs			20	100					
Projected on-hand	20	5	5	55	45	15	-15	-15	
New requirements							15	30	30
Planned order receipts							45		30
Planned order releases					45		30		

Table 6: MRP Example (Hopp & Spearman, 2008)

This is an effective model for eliminating inventory, however if demand is in flux and not known, the system may not work effectively.

Chapter 3: Models and Calculations

3.1 Description and Verification of Key Data

Section 1.5 introduced two key points of data needed in order to assure accurate demand forecasting for a firm using job-based production. Below is a further explanation of both the project schedule and the bid success probability that are needed. The bid success probability will also be evaluated in order to determine its accurateness when compared to historical results. This evaluation will provide the verification needed in order to show that past success probabilities listed for projects are accurate and can continue to be used in the future. While these probabilities and the formulas used to calculate them may change in the future as more accurate ways for determination are found, it is important to ensure a solid baseline.

3.1.1 Project Schedule

One of the most important parts of a job-based manufacturing system is the project schedule that is used for each specific project. This project schedule outlines all major milestones of a project as well as the necessary steps to complete each milestone. For each step the duration needed for completion, predecessor tasks, successor tasks, and start and end dates (frequently based on predecessors and successors) are determined and listed. Project schedules may be high-level, showing mostly general details and milestones, or as detailed as is required by the company, client, and project manager. A sample project schedule is given in Illustration 3.

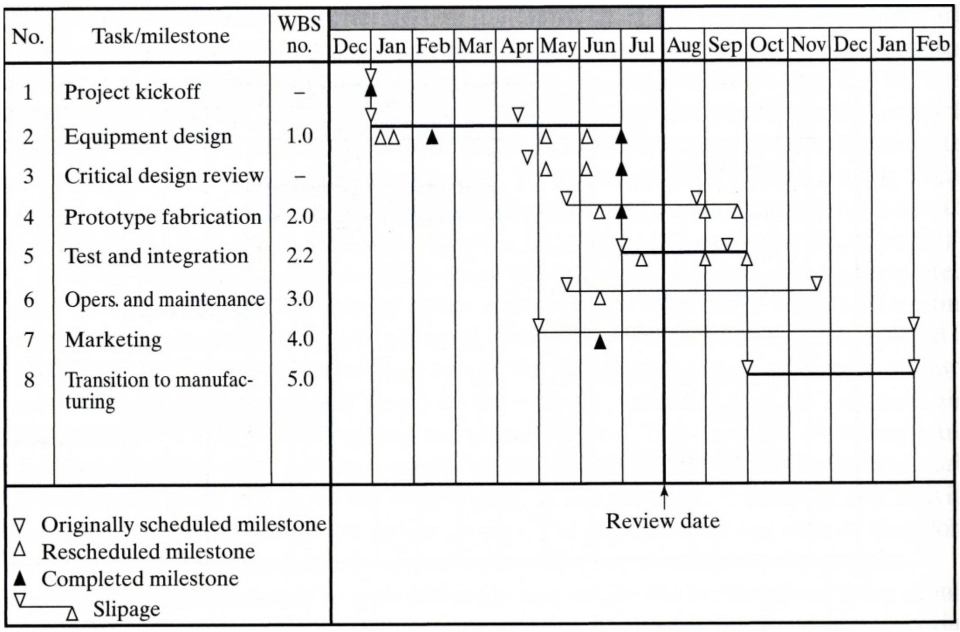

Illustration 3: Sample Project Schedule (Bard, Shtub, & Golberson, 2005)

3.1.2 Bid Success Probabilities

3.1.2.1 Description

As discussed in Section 1.4.2, in order to determine what demand could potentially be realized in the future, the probability of winning an outstanding bid must be known. Once that information is determined, the methods and calculations explained later in this report will help a company determine whether or not there is a significant demand to allow for the purchase of components for projects whose customer demand has not yet been realized. The method of calculating this data will vary between companies and industries. Furthermore, the means of how this information is calculated is considered highly confidential and proprietary information to the company using it. If the information were to become public it would be possible for competitors to gain an advantage, especially in the competitive bidding aspects of the business. There are also different types of bidding that can affect the overall probability that the bid is successful. The common types of bidding are described below in Table 7.

Type of Approach	**Characteristics of Approach**
Adaptive Approach	Firm reacts to the market Primary Strategy is to bid low and bid often (low margin, high turn). Markup over cost will vary according to recent success or failure and current workload
Quantitative Approach	Markup percentage is based on number of competitors, size of bid, and competitors' past performance. Firm uses probability model to estimate expected profit at a given price. Primary goal is profit maximization.
Strategic Approach	Bid price is based on an estimate of the "value" of the job. Bidding is selective-targeted at opportunities most likely to meet company objectives. Primary goal is long-term value creation for the organization.

Table 7: Types of Bidding Approaches (Boughton, 1987)

One critical aspect is to verify that the bid success probability for each project is accurate. This is done by verifying data from past projects that were bid and determining how accurate each bid success probability actually was. For example, if you find that of 15 projects that were rated a 75% or higher bid success probability, only 20% were actually deemed successful, then the calculations metrics need to be adjusted. On the contrary, if 75% of those 15 projects were deemed successful, then there is confidence in the data and calculations being used.

3.1.2.2 Verification of previous project bids

In order to validate the method described above in Section 3.1.2.1 it is necessary to look at data from past project proposals. All past closed projects are evaluated and listed as either successful or inactive. These projects were closed due to a winning bid, i.e., a contract was signed, or were classified as inactive because another bidder won the project, the company withdrew the project, the company lost funding, or a multitude of other reasons ranging from the company itself, investors, other parties involved, government reasons, or taxes. Due to the proprietary nature of this information it cannot be shown in detail; however, an excerpt is shown in Table 8 in order to understand the setup of the data.

Project Code	Bid Success Probability	Status
Osaka	10%	Inactive
Berlin	30%	Contracted
Changchun	40%	Inactive
Guadalajara	80%	Contracted

Table 8: Bid Success Probability Analysis Excerpt

The methods can be explained as well as conclusions drawn from this data. The data was first evaluated in quartiles with the project in each quartile being summed to determine a success factor for each quartile. This method was then used for both quintiles and then a customized range. The results of this are shown in Table 9.

	Quartiles			
	0-25%	26%-50%	51%-75%	76%+
% Success	5%	67%	100%	100%
	Quintiles			
	1-20%	21%-40%	41-60%	61-80%
% Success	0%	75%	71%	100%
	Customized Range			
	1-20%	21%-49%	50-79%	80%+
% Success	0%	71%	80%	100%

Table 9: Bid Success Probabilities Evaluation

Based on Table 9, we see immediately that the upper and lower ranges, i.e., 0-25% and 76%+ for quartiles, have success percentages that fall within each respective range. This reflects an accurate representation as the total success percentage for that range fell within its expected criteria, the range itself. In terms of project bidding this means, if a project is determined to have a low bid success probability it is generally not won and if it determined to have a high bid success probability it is generally won. However the middle range, i.e., 26-50% and 51-75% for quartiles, is more complicated. For the middle two quartiles the total success percentages do not fall within each respective range, the quartile 26-50% has a success rate of 67%. However, these results are better than expected since each has a total percentage greater than its range. For the purposes of this report we will assume that this allows us to continue on using the data that has been provided.

3.2 Methods

In order to determine the best possible method of forecasting inverter and power cell demand for XP the use of four different, however similar, methods are proposed. Each tries to maintain a simple approach that allows adaptability into any industry.

3.2.1 Method 1

The first method is used as a baseline for all other methods used later in this report. In Section 3.1 the bid success probability was described and evaluated in order to determine the likelihood of a company landing the project bid. In addition, the project schedule, as described above in Section 3.1.1, can be used to determine the quarters in which both power cells and inverters for each project are needed. If the project component demands are spread over multiple quarters then the appropriate number of inverters and power cells are allocated for demand in each quarter as dictated by the project schedule. The bid success probability and component demand data for each project will remain constant throughout all methods. Method 1 will take the raw bid success probabilities and multiply it by the quarterly component demand. This will yield the expected number of power cells and inverters demanded by each project on a quarterly basis.

3.2.2 Method 2

Method two expands on method one by taking into account some of the information that was concluded from Section 3.1.2.2. Projects that have a high bid success probability will be considered won and projects with a low bid success probability will be considered inactive. The range will also be found that finds the best case scenario (upper bound), average, and worst case scenario (lower bound). For each scenario if a project bid is not deemed likely of being successful, it will be deemed inactive. The lower bound in this method is described as the practical worst case scenario because this is the minimum demand a company expects. As described in Section 3.1.2.2 certain ranges of bid success probabilities are determined to be ‘safe’ bids and can be considered won. Verification of this data shows that the likelihood of a project with a bid success probability of over 75% being won is very good. Therefore as a worst case scenario, any project with a success probability greater than or equal or 75% will have its probability defined as 100%. All other projects will then be considered inactive, with a probability of 0. The same process will be used for determining an average range, where the bid success probability will be considered won and all others will be considered inactive, and a best-case scenario, where a bid success probability above 25% will be considered won and all others will be considered inactive.

3.2.3 Method 3

Method three is similar to method two with ranges that find the upper bound, average, and the lower bound. The same values for bid success probability cut-offs as in method two will be used in method three. However, in this method, if a project is not considered won it will remain active with a probability equal to its bid success probability rather than being considered inactive.

3.2.4 Method 4

Method four will allow for projects with a high bid success probability to be deemed a success and projects with a low bid success probability to be deemed inactive. Projects in between the two will use the bid success probability in order to calculate their demand forecast. Any bid success probability greater than 75% will be considered won, and bid success probability less than 25% will be considered inactive and all others will use the bid success probabilities given.

3.3 Calculations

Detailed calculations for each of the methods described in Section 3.2 are shown. Each method will also use the sample problem described in Section 1.2 to illustrate its use. A description of the nomenclature used can be found following the appendix. However the indices used are as follows:

$x \in X$ – set of all components $x \ \forall \ x = 1,2$

$y \in Y$ – set of all project $y \ \forall \ y = 1, \dots, 91$

$z \in Z$ – set of all quarters $k \ \forall \ k =$ Q2 2012, … , Q4 2013

3.3.1 Method 1 Calculation

Method 1 described in Section 3.2.1 is formulated as

$$d_{x,z} = \sum_{y \in Y} P_y * D_{xyz} \ \forall \ x, z \tag{6}$$

This formula takes into account the quarterly demand for each component in a project. The demand needed for each component in a project is then multiplied by its bid success probability. This expected demand is then summed over all existing projects and the final output is the total expected quarterly demand for each component. The sample problem in Section 1.2 and outlined in Table 1 will be used in order to demonstrate Method 1. Method 1 yields the calculations in Table 10 for each of the projects as well as the overall quarterly demand for each component (assuming there are no other projects with demand in quarter one).

	Expected Demand	
	Power Cells	Inverters
Project A	750	0.75
Project B	4000	2
Project C	1250	1.25
Quarter 1	6000	4

Table 10: Method 1 Outcome for Sample Problem

A main advantage to this method is its simplicity and straightforwardness give a good idea on what type of volume to expect on a quarterly basis. There is also incentive to provide an inventory of these amounts for each component to be ready for utilization in quarter 1. However, each project success is binary, i.e. the project will either be won, demand will be recognized, or it will be inactive, and demand will not be recognized. This means that the 6000 power cells and 4 inverters represent the expected demand for the sample problem under Method 1. When compared to the potential outcomes of the sample problem, listed in Table 2, note that the expected demand does not equal any possible outcome meaning an excess or shortage will occur.

Under this forecast, four of the outcomes will fall experience a shortage, potentially delaying the project, and four of the outcomes will have an excess, resulting in holding costs of unused equipment. In this industry, with the length of lead times that are common, ordering components in advance will provide for a shorter production lead time regardless of whether or not projects are won. In the event of excess units, components are held in inventory for a longer period of time. These components can always be used by future projects and hopefully would not sit in inventory for more than one quarter. However, there will be costs associated with hold them which will cause a reduction in the profit of margin of the project in which they are eventually used for. For example if an inverter costs $100,000 and is placed in inventory, the expected annual holding cost is $30,000, based on the information from Section 2.2.

3.3.2 Method 2 Calculation

Method 2 which is an expansion on Method 1. Method 2 has 3 parts which incorporate a lower bound, average, and an upper bound. The lower bound in this method is described as the practical worst case scenario. As described in Section 3.2.2, there are certain ranges of probability of successes that correspond to the lower bound, average, and upper bound.

The lower bound is formulated as follows:

$$W_y = \begin{cases} 1 & if\ P_y \geq 0.75 \\ 0 & if\ P_y < 0.75 \end{cases} \tag{7}$$

$$d_{x,z} = \sum_{y \in Y} W_y * D_{xyz}\ \forall\ x, z \tag{8}$$

The average for this method will be similar to the formulation of the lower bound but will be cutoff at 50%. The validation of the bid success probabilities from Section 3.1.2.2 shows there is a demarcation line between probabilities that are over and under 50%:

$$W_y = \begin{cases} 1 & if\ P_y \geq 0.5 \\ 0 & if\ P_y < 0.5 \end{cases} \tag{9}$$

$$d_{x,z} = \sum_{y \in Y} W_y * D_{xyz}\ \forall\ x, z \tag{10}$$

The upper bound in this method is described as the realistic best case scenario. As described in Section 3.2.2, there are certain ranges of bid success probabilities that are considered 'inactive bids.'

The upper bound is formulated as shown in formulas (11) and (12):

$$W_y = \begin{cases} 1 & if\ P_y > 0.25 \\ 0 & if\ P_y \leq 0.25 \end{cases} \tag{11}$$

$$d_{x,z} = \sum_{y \in Y} W_y * D_{xyz}\ \forall\ x, z \tag{12}$$

The same example from Section 1.2 will be used to examine Method 2 as shown in Table 11.

	Lower Bound		Average		Upper Bound	
	Power Cells	Inverters	Power Cells	Inverters	Power Cells	Inverters
Project A	1000	1	1000	1	1000	1
Project B	0	0	8000	4	8000	4
Project C	0	0	0	0	5000	5
Quarter 1	1000	1	9000	5	14000	10

Table 11: Method 2 Outcome for Sample Problem

One advantage to this method is that it implements a range which can help to alleviate some of the precision needed in demand forecasting. Again, each project success is binary, i.e. the project will either be won and the entire demand will be recognized or it will be lost and none of the demand will be recognized. This means that the forecast will provide only an estimate of demand and may not equate exactly to one a certain potential outcome. The lower bound, average, and upper bound for each component can be compared to the potential outcomes of the sample problem listed in Table 2.

Under this forecast for Method 2 the average shows that four of the scenarios will experience a shortfall of components and four of the scenarios will have excess components. In the lower bound, all but two scenarios have excess components and for the upper bound all but one scenario fails to meet the forecast. As stated above, any shortages may result in project delays and any excess will result in inventory holding costs.

3.3.3 Method 3 Calculation

Method 3 follows up on Method 2 but attempts to minimize the range between the lower and upper bound. A more precise range yields helps to narrow the demand forecast. This range is beneficial to a company as it allows a forecast to increase or decrease based on factors such as economic or financial changes, current inventory stock levels, or a change in the risk willingness of a company. This is accomplished by allowing any bid success probabilities that do not meet the criteria of a particular bound to be set to P_y instead of 1 or 0, as was the case in Method 2. This gives any project a chance of being successful and assigns certainty only to projects that meet the specified criteria. Similar to Method 2, Method 3 also has a lower bound, average, and upper bound.

The lower bound is formulated as follows:

$$W_y = \begin{cases} 1 & if\ P_y \geq 0.75 \\ P_y & if\ P_y < 0.75 \end{cases} \tag{13}$$

$$d_{x,z} = \sum_{y \in Y} W_y * D_{xyz}\ \forall\ x, z \tag{14}$$

The average of this method will be cutoff at 50%, like its counterpart in Method 1. This average is shown as follows:

$$W_y = \begin{cases} 1 & if\ P_y \geq 0.5 \\ P_y & if\ P_y < 0.5 \end{cases} \tag{15}$$

$$d_{x,z} = \sum_{y \in Y} W_y * D_{xyz}\ \forall\ x, z \tag{16}$$

The upper bound in this method is described as the best case scenario. For the same reasons as described above in Method 2 the upper bound is formulated as:

$$W_y = \begin{cases} 1 & if\ P_y > 0.25 \\ P_y & if\ P_y \leq 0.25 \end{cases} \tag{17}$$

$$d_{x,z} = \sum_{y \in Y} W_y * D_{xyz}\ \forall\ x, z \tag{18}$$

The same problem from Section 1.2 will again be used to demonstrate Method 3. The following results are obtained for the lower bound, average, and upper bound for each project as shown in Table 12.

	Lower Bound		Average		Upper Bound	
	Power Cells	Inverters	Power Cells	Inverters	Power Cells	Inverters
Project A	1000	1	1000	1	1000	1
Project B	4000	2	8000	4	8000	4
Project C	2500	2.5	2500	2.5	5000	5
Quarter 1	7500	5.5	11500	7.5	14000	10

Table 12: Method 3 Outcome for Sample Problem

One of the main advantages to this method, as discussed above, is that it is compresses the range between lower bounds and upper bounds. This enables a company to allow confidently determine a range in which the demand is likely to fall rather than settling on one particular number. A company can then use the factor discussed above to determine where to place an order within the range. Method 2 has a power cell range of 13,000. However, Method 3 has reduced that to 6,500. This is the same for the inverter range going from 9 in Method 2 to 4.5 in Method 3. Method 2 provided data that created ranges that were too large to be able to accurately estimate the expected demand. The same incentive to provide an inventory of these amounts for each component for utilization in quarter 1 still exists. While there is no guarantee that the ordered amount will exactly equal demand, the narrowed range helps eliminate the possibility of having a large unit excess or shortage. The ranges from Table 12 can be compared to the potential outcomes of the sample problem in Table 2. Under this forecast for Method 3, six of the scenarios will experience components shortfalls compared to average and two of the scenarios will have unit excess. This is also true the lower bound. The upper bound has all but one scenario with excess components.

3.3.4 Method 4 Calculation

Method four takes many of the pros that were found in Methods 1, 2, and 3 and tries to capitalize on them. The method is formulated by setting the probability of success to 0% for any project whose bid success probability is less than 25%. It sets the probability of success to 100% for any project whose probability of success is greater than 75%. Any bids not covered in these ranges will use their P_y value for evaluation. The method estimates the demand as follows:

$$W_y = \begin{cases} 1 \ \ if\ P_y \ \geq 0.75 \\ P_y \ \ if\ 0.25 \ \leq P_y < \ 0.75 \\ 0 \ \ if\ P_y \ < 0.25 \end{cases} \tag{19}$$

$$d_{x,z} = \sum_{y \in Y} W_y * D_{xyz} \ \forall\ x, z \tag{20}$$

The same sample problem from Section 1.2 will be used for this method. Implementing formulas (19) and (20) the following results are obtained for each project as shown in Table 13.

	Expected Demand	
	Power Cells	Inverters
Project A	1000	1
Project B	4000	2
Project C	1250	1.25
Quarter 1	6250	4.25

Table 13: Method 4 Outcome from Sample Problem

One of the main advantages to this method is it creates certainty assumptions for projects that have high or low bid success probabilities. This expected demand can be compared to the potential outcomes of the sample problem found in Table 2. When compared to Table 2, four of the scenarios will experience component shortfall and four of the scenarios will have component excess.

Chapter 4: Data and Analyses

4.1 Data collection

The methods described in Section 3 are applied to the XP data set. This data consists of 91 different projects which take place between the end of 2010 and the end of 2013. The inverter and powercell demands are calculated for each project based on a general formula that is derived from the project schedule. These demands are allocated to their respective quarters and the demand for that quarter is summed up over all projects. Ultimately a single demand number is provided for a component per quarter.

Due to the proprietary nature of the data it cannot be shared in its entirety in order to protect the best interest of XP, its clients, and the author. However, a list of projects along with each project's bid success probability, and inverter and power cell demand is provided in the appendix. A sample excerpt of this information is shown in Table 14.

Project Name	Probability	# of Inverters Needed	# of Power Cells Needed
Tokyo	0%	6	6,000
Seoul	45%	6	6,000
Mexico City	70%	4	4,000

Table 14: Sample Excerpt of Project Data

This project data also provides the dates for contract execution and required commercial delivery date (COD) from the customer, which can be used to calculate the dates for installing the first and last of the necessary components in a project. These dates are estimated assessing the testing, shipping, installation, and commissioning times of the project based on their ratings. Samples of the timeframes based on the number of inverters in a project, are shown in Table 15.

Minimum Number of Inverters	Maximum Number of Inverters	Testing Time	Installation time	Commissioning Time
1	4	4 weeks	2 weeks	2 weeks
5	8	6 weeks	4 weeks	2 weeks
9	12	8 weeks	6 weeks	3 weeks
13	18	10 weeks	8 weeks	3 weeks
19	25	12 weeks	10 weeks	4 weeks
26	50	16 weeks	12 weeks	6 weeks
51	100	20 weeks	16 weeks	8 weeks
101	200	28 weeks	20 weeks	12 weeks

Table 15: Inverter Timeframe Ranges

This input allows the inverter and power cell demand for each project to be accurately portrayed. Component demand for each project is determined, using the same data set in order to evaluate each of the methods discussed in Section 3.3

4.2 Demand Forecast

4.2.1 Assumptions

Prior to modeling the demand forecast for each of these methods several assumptions must be made in order to clarify the actual situation. These assumptions are as follows:

1. Any project contracted is considered to have a bid success probability of 100%

2. Any project that becomes inactive is considered to have a bid success probability of 0%
3. Capacity is available for the procurement of both inverters and batteries or can be adjusted to be able to accommodate.
4. Only projects which are known currently in the project bidding process will be under consideration.
5. The outlook is over a timeframe of 7 quarters (21 months).

4.2.2 Demand Forecast

The demand forecast results are tabulated for each of the four methods described in Section 3.3 is analyzed in Table 16.

		Forecasted Quarterly Inverter Demand						
		Q2 2012	**Q3 2012**	**Q4 2012**	**Q1 2013**	**Q2 2013**	**Q3 2013**	**Q4 2013**
Method 1		18.95	8.35	12.65	15.15	7.7	5.55	2.1
Method 2	**Lower**	14	1	1	0	0	0	0
	Average	14	2	3	5	0	0	0
	Upper	25	18	33	41	20	13	7
Method 3	**Lower**	18.95	8.35	12.65	15.15	7.7	5.55	2.1
	Average	18.95	8.85	13.35	16.9	7.7	5.55	2.1
	Upper	25.55	19.15	33.5	42.3	21.1	14.7	7.35
Method 4		18.4	7.2	12.15	13.85	6.6	3.85	1.75

Table 16: Forecasted Quarterly Inverter Demand

A visual representation of the demand forecasts is shown below in Figure 2. One can immediately see the similarities between demand curves of Methods 1, 3 and 4. The demand curve for Method 2 is significantly lower than the other three.

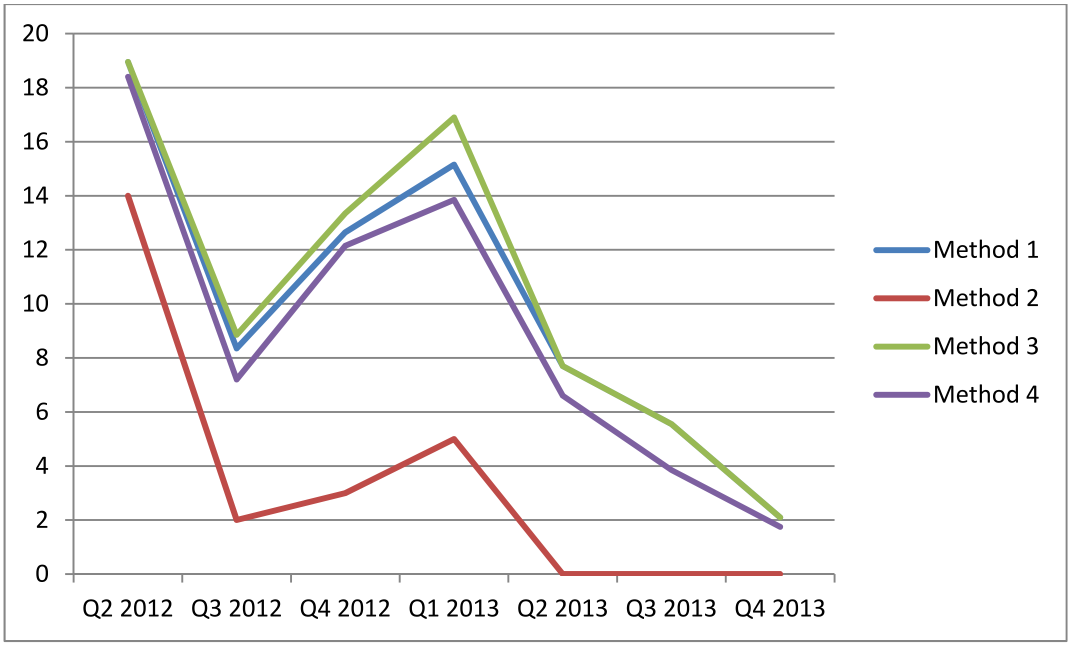

Figure 2: Inverter Demand Forecasting Methods Comparison

The same analysis is carried out for the power cells. The power cell demand forecast is shown in Table 17.

		Forecasted Quarterly Power Cell Demand						
		Q2 2012	**Q3 2012**	**Q4 2012**	**Q1 2013**	**Q2 2013**	**Q3 2013**	**Q4 2013**
Method 1		20600	12750	21450	38300	21600	11500	3200
Method 2	**Lower**	14000	1000	100	0	0	0	0
	Average	14000	2000	2100	6000	0	0	0
	Upper	25000	22000	57100	107000	51000	21000	9000
Method 3	**Lower**	20600	12750	21450	38300	21600	11500	3200
	Average	20600	13250	22150	38300	21600	11500	3200
	Upper	27200	26050	59350	111600	55300	25900	9950
Method 4		18400	8700	19200	33700	17300	6600	2250

Table 17: Forecasted Quarterly Power Cell Demand

A visual representation of power cell demand forecasting is shown below in Figure 3. Similar to the inverter demand forecasting, Method 2's forecast is significantly lower than the other three. Also Method 4 is consistently lower than both Methods 1 and 3. The difference, however, is small.

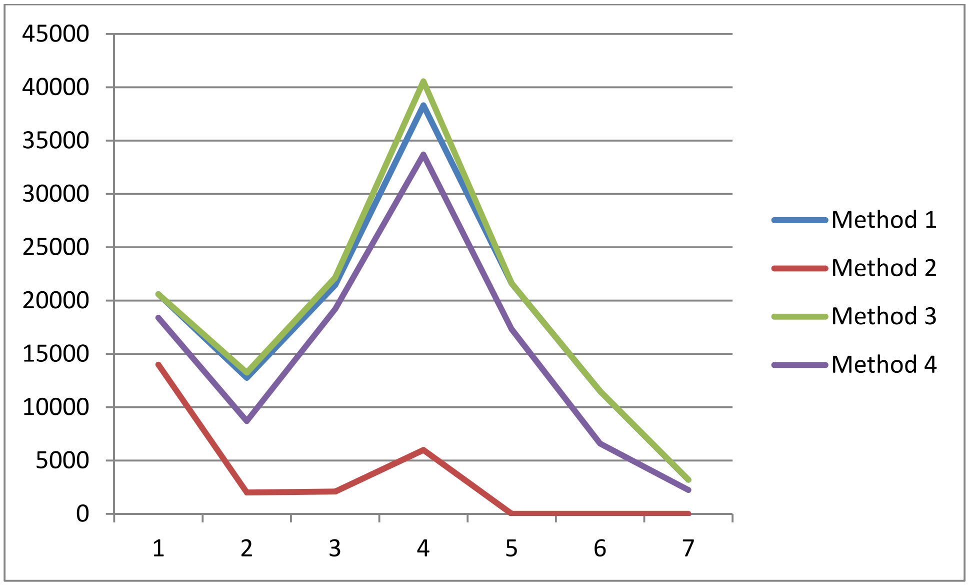

Figure 3: Power Cell Demand Forecasting Methods Comparison

4.3 Historical Data Analysis

While the inverter and power cell demand forecasting models in Section 4.2 show reasonable forecasts, it is impossible to determine the accuracy of these models without evaluating them against known data. In order to do this, past data, in which the actual demand is known, must be used. Seven previous quarters will be evaluated starting with quarter 3 of 2010 and ending with quarter 1 of 2012. The demand forecasting that is made along with the actual demand during that time frame for inverters is in Table 18.

		Historical Forecasted Quarterly Inverter Demand						
		Q3 2010	**Q4 2010**	**Q1 2011**	**Q2 2011**	**Q3 2011**	**Q4 2011**	**Q1 2012**
Actual		4	6	2	0	2	3	18
Method 1		0.4	2.45	3.7	11.2	15.15	19.5	25.3
Method 2	**Upper**	0	0	3	7	1	0	1
	Lower	0	2	3	7	1	6	7
	Median	0	3	3	21	45	58	76
Method 3	**Upper**	0.4	2.45	4.3	12.6	15.35	19.5	25.5
	Lower	0.4	3.35	4.3	12.6	15.35	21.5	27.6
	Median	0.4	4.1	4.3	23.1	47.2	58.55	76.55
Method 4		0	1.35	3	10.5	13.15	18.95	24.95

Table 18: Historical Forecasted Quarterly Inverter Demand

A visual representation of this demand forecast compared to the actual is shown in Figure 4. The actual demand is shown as the dashed line in the figure to differentiate from the forecast models.

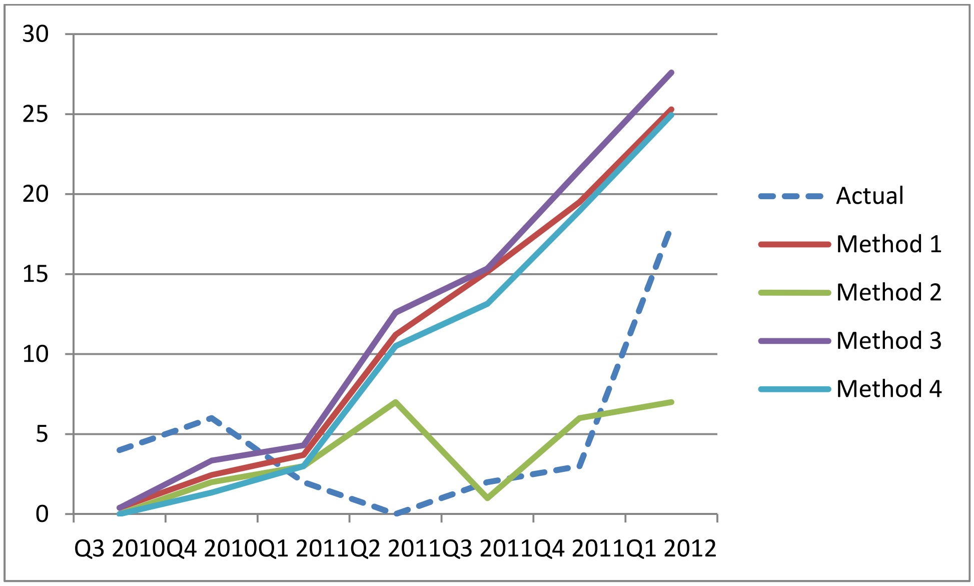

Figure 4: Comparison of Historical Inverter Demand Forecasts to Actual Demand

At some point, the methods provide inverter forecasts that are within one or two units of the actual during some quarters, i.e. Q1 2011 in which all four methods provide a forecast that is within two units of the actual. However during other quarters there is a large difference between the actual and the forecast, i.e. Q2 2011 whenever Methods 1, 3, and 4 predicted. Similar to the inverter forecasting, power cell demand forecasts are listed in Table 19. These methods are visually compared in Figure 5.

		Historical Forecasted Quarterly Power Cell Demand						
		Q3 2010	**Q4 2010**	**Q1 2011**	**Q2 2011**	**Q3 2011**	**Q4 2011**	**Q1 2012**
Actual		0	6000	3000	0	2000	6000	25000
Method 1		1700	6100	8600	45250	84800	83900	88700
Method 2	**Median**	0	0	5000	14000	2000	0	1000
	Upper	0	2000	5000	14000	2000	7000	7000
	Lower	0	4000	5000	126000	298000	307000	323000
Method 3	**Median**	1700	6100	9600	48050	85200	83900	88900
	Upper	1700	7000	9600	48050	85200	86400	91000
	Lower	1700	8500	9600	132050	305300	309450	325200
Method 4		0	1600	5000	42000	77900	81450	86700

Table 19: Historical Forecasted Quarterly Power Cell Demand

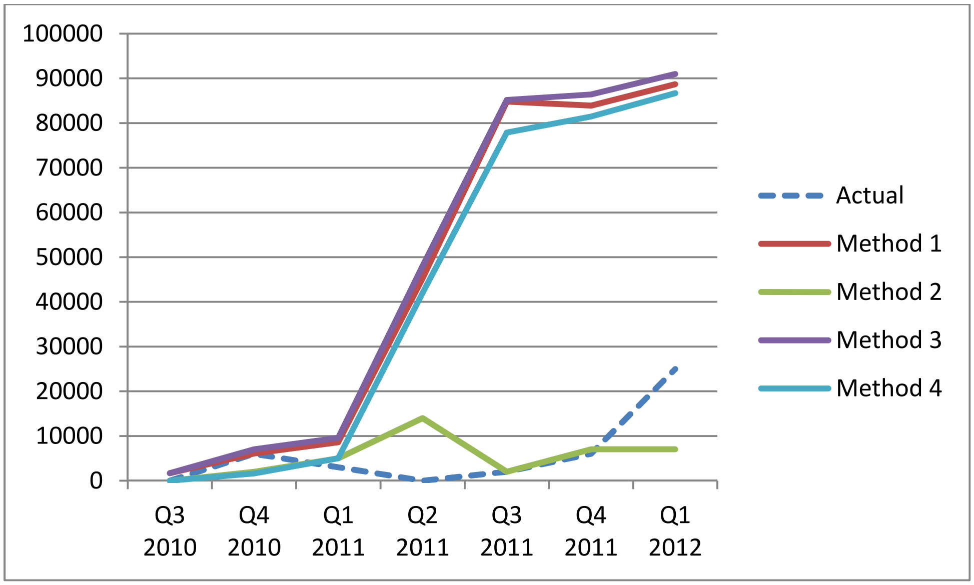

Figure 5: Comparison of Historical Power Cell Demand Forecasts to Actual Demand

Upon evaluating both the inverter and power cell forecasting models it is evident that a large discrepancy is present during some quarters, i.e. Q3 2011 whenever demand forecasts for methods 1, 3, and 4 forecasted between 80,000 and 90,000 power cells when actual demand was 2000. Method 2 forecasted a demand of 0, much closer to the actual. This leads to the question: Why do Methods 1, 3, and 4 track to actual demand for quarters in which demand is low, i.e. below 25,000, but not others? Evaluation of the data shows one reason for this large difference is due to several large projects, in which at least 50 inverters are demanded at the specific time, being present in those quarters. For instance a large scale project may have a 20% bid success probability and be demanding 35 inverters and 200,000 power cells in Q3 of 2011. This would mean that some methods may allocate around 7 inverters and 40,000 power cells in a quarter. If several of these projects occur at the same times the forecasts can be abnormally high. Removing these large scale projects, and analyzing them on a case by case basis, may allow for a more accurate forecast.

4.4 Modified Historical Data Analysis

Removing large scale projects in which 50 or more inverters are used may create a more accurate demand forecast. These outliers may be better evaluated in a separate analysis due to their size difference from smaller projects in the model. Historical demand forecasting under this criteria is shown in Table 20 and visually compared in Figure 6.

		Modified Historical Forecasted Quarterly Inverter Demand						
		Q3 2010	**Q4 2010**	**Q1 2011**	**Q2 2011**	**Q3 2011**	**Q4 2011**	**Q1 2012**
Actual		4	6	2	0	2	3	18
Method 1		0.4	2.45	3.7	11.2	15.15	19.5	25.3
Method 1 (Modified)		0	1.35	2.6	6.4	4.75	10.2	16
Method 2	**Upper**	0	0	3	7	1	0	1
	Lower	0	2	3	7	1	6	7
	Median	0	3	3	21	45	58	76
Method 2 (Modified)	**Upper**	0	0	3	7	1	0	1
	Lower	0	2	3	7	1	6	7
	Median	0	3	3	7	10	23	41
Method 3	**Upper**	0.4	2.45	4.3	12.6	15.35	19.5	25.5
	Lower	0.4	3.35	4.3	12.6	15.35	21.5	27.6
	Median	0.4	4.1	4.3	23.1	47.2	58.55	76.55
Method 3 (Modified)	**Upper**	0	1.35	3.2	7.8	4.95	10.2	16.2
	Lower	0	2.25	3.2	7.8	4.95	12.2	18.3
	Median	0	3	3.2	7.8	10.55	23	41
Method 4		0	1.35	3	10.5	13.15	18.95	24.95
Method 4 (Modified)		0	1.35	3	7	4.4	10.2	16.2

Table 20: Modified Historical Forecasted Quarterly Inverter Demand

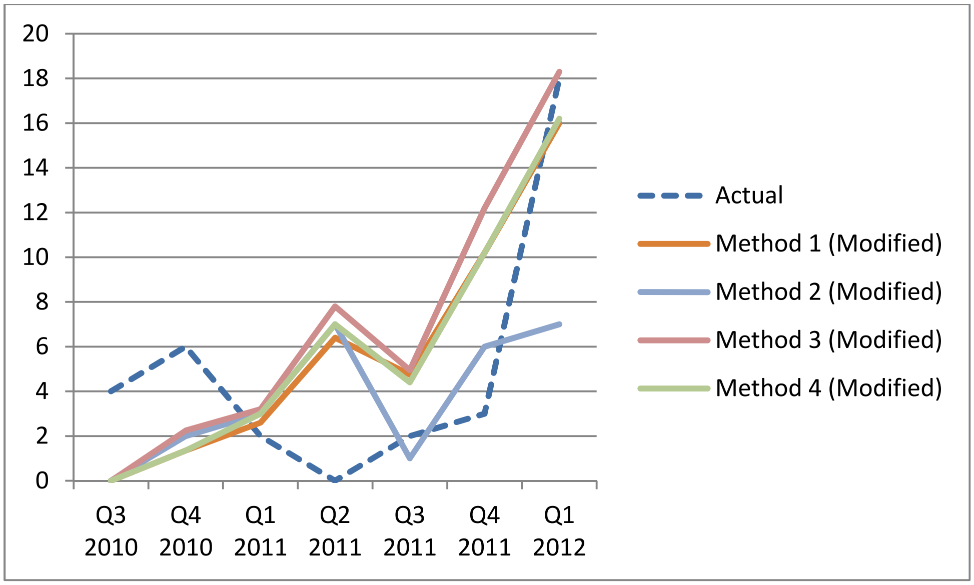

Figure 6: Comparison of Modified Historical Inverter Demand Forecasts

Inverter demand shows some improvement over the historical forecasting shown in Section 4.2. Power cells show similar results as shown in Table 21 and in Figure 7 as compared to Section 4.2.

		Modified Historical Forecasted Quarterly Power Cell Demand						
		Q3 2010	**Q4 2010**	**Q1 2011**	**Q2 2011**	**Q3 2011**	**Q4 2011**	**Q1 2012**
Actual		0	6000	3000	0	2000	6000	25000
Method 1		1700	6100	8600	45250	84800	83900	88700
Method 1 (Modified)		0	1600	4200	12000	7550	10950	16750
Method 2	**Median**	0	0	5000	14000	2000	0	1000
	Upper	0	2000	5000	14000	2000	7000	7000
	Lower	0	4000	5000	126000	298000	307000	323000
Method 2 (Modified)	**Median**	0	0	5000	14000	2000	0	1000
	Upper	0	2000	5000	14000	2000	7000	7000
	Lower	0	4000	5000	14000	16000	25000	44000
Method 3	**Median**	1700	6100	9600	48050	85200	83900	88900
	Upper	1700	7000	9600	48050	85200	86400	91000
	Lower	1700	8500	9600	132050	305300	309450	325200
Method 3 (Modified)	**Median**	0	1600	5200	14800	7950	10950	16950
	Upper	0	2500	5200	14800	7950	13450	19050
	Lower	0	4000	5200	14800	16550	25000	44000
Method 4		0	1600	5000	42000	77900	81450	86700
Method 4 (Modified)		0	1600	5000	14000	7400	10950	16950

Table 21: Modified Historical Forecasted Quarterly Power Cell Demand

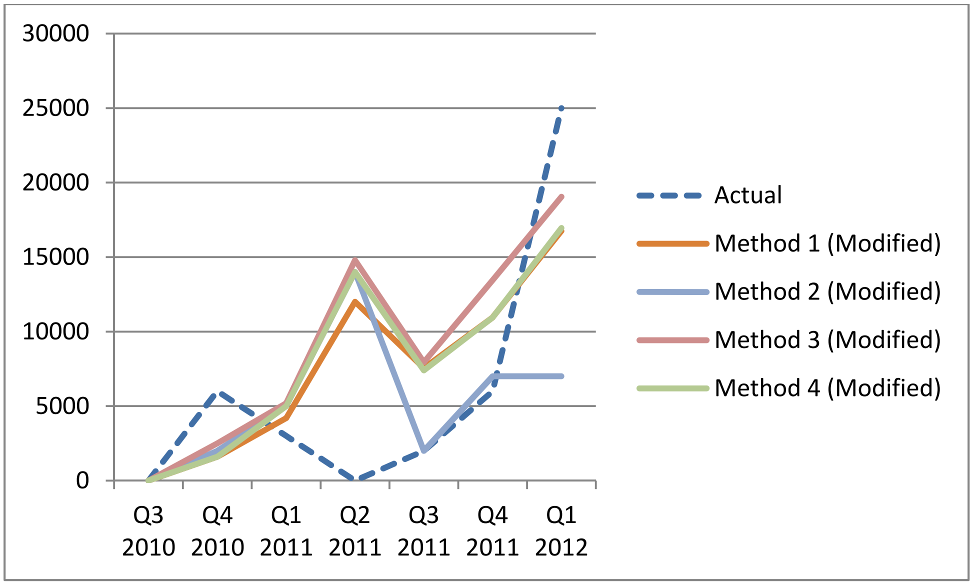

Figure 7: Comparison of Historical Inverter Demand Forecasts without Outliers

From the modified historical demand forecast for both inverters and power cells it can be deduced that the demand curves are now more accurate and coincide with the actual values more than with the outliers included, as shown in Section 4.2. In order to further evaluate this as well as determine the best method to use for forecasting, each method must be evaluated for error.

4.5 Error Analysis

It is important to calculate a confidence in these methods by determining how accurate they are to forecasting demand. In order to do this, the same method can be applied, but pushed to a date in the future in which the outcomes are known. In this case, the calculations were redone from a point in time spanning from Quarter 3 of 2010 to Quarter 1 of 2012. Since the actual demands, along with outcomes of project bids, are known, the forecasted demand can then be compared to the actual demand.

Conducting an error analysis on this data can provide a basis for choosing one particular method or another to use for future demand forecasting. In order to provide error estimate for each method, the error of the forecasted demand relative to the actual is calculated. For error analysis the mean squared error will be used on each method, the formula for which is shown as:

$$MSE_x = \frac{1}{N-1}\sum_{z \in Z}(d_{x,z} - \overline{d_{x,z}})^2 \; \forall \, x \tag{21}$$

The MSE for each of the methods is calculated using formula (21) for both inverters and power cells. The result is shown in Table 22.

	Inverter Error	**Power Cell Error**
Method 1	19802.55	1.74144E+19
Method 1 (Modified)	780.1268	4.54842E+15
Method 2	2215.333	2.39414E+16
Method 2 (Modified)	2215.333	2.39414E+16
Method 3	29490.25	1.90016E+19
Method 3 (Modified)	1823.601	8.95608E+15
Method 4	15271.4	1.38663E+19
Method 4 (Modified)	901.2339	7.40882E+15

Table 22: MSE Error Analysis of Methods

Prior to modifying the data, Method 2 had the lowest MSE far surpassing Methods 1, 3, and 4. However upon removing the outlier projects that were causing falsely high forecasts Method 2 became the worst, having the highest MSE. This proved to be true for both inverters and power cells. This is not surprising for Method 2, being the strictest of the methods in which projects are either won or lost with no possibility for success. This strictness helped to discount the large projects originally, however after modification the it was better to allow for project to be won, lost, and possible, which Methods 1, 3, and 4 provide. Based on the error analysis, Method 1 with modified data is the best demand forecasting method to use.

Chapter 5: Conclusion

5.1 Report Conclusions

After evaluating all of the methods choosing one to put into place becomes the greatest challenge for a company. As seen from Table 22, the MSE of the methods change significantly once outliers were removed from the data set. This emphasizes the point that it is important to focus on evaluating only a core product. Reserving a separate analysis for situations which are outliers is better as these projects would likely cause enough of a change in the company that it is worth re-evaluating the forecast. Both inverters and power cells yielded the lowest MSE with Method 1, followed closely by Method 4. This is of no great surprise since the randomness of the problem the opportunity to successfully bid any project always exists. The most important aspect is that as a company implements a demand forecasting model, it should be evaluated from time to time and adapted to meet any industry and economical changes. A forecasting model is only as good as the input data. All data should be verified and checked for inaccuracies. If bid success probabilities begin to be less accurate, the way in which they are calculated should be redefined as the forecasts deviate from the actual if they are not corrected. Keeping a simple forecasting method helps allow for adaptations in the future, benefitting the company.

5.2 Future Work and Research

There are several extensions to this work that can be done for further improving this research and for increasing its potential. First, this report only looks at two components. In most cases, many additional critical components are involved in the final product and could be added in order to analyze their demand on a quarterly basis. Second, an extension of the supply chain and inventory management required for a problem of this nature would provide further significant benefits to a company. Third, developing a more accurate and thorough method of determining factors such as bid success probabilities will only help to strengthen the accuracy of demand forecasting. Lastly, there are many other methods that can be used to forecast demand ranging from simple calculation with only a few inputs, to complex calculation that utilize entire data sets. Finding the most accurate method of forecasting and verifying it with real data is the best way to establish accurate forecasting.

Appendix

Appendix A : Project List

Project Name	Probability	# of Inverters Needed	# of Power Cells Needed
Tokyo	0%	6	6,000
Seoul	45%	6	6,000
Mexico City	70%	4	4,000
New York	35%	2	4,000
Mumbai	0%	1	1,000
Jakarta	25%	2	2,000
Sao Paulo	5%	50	200,000
Delhi	80%	10	20,000
Osaka	10%	50	200,000
Shanghai	0%	1	2,000
Manila	0%	1	2,000
Los Angeles	0%	2	4,000
Calcutta	35%	1	4,000
Moscow	35%	3	12,000
Cairo	5%	2	2,000
Lagos	25%	1	1,000
Buenos Aires	0%	1	1,000
London	25%	2	4,000
Beijing	30%	1	2,000
Karachi	0%	2	8,000
Dhaka	40%	1	4,000
Rio de Janeiro	40%	2	8,000
Tianjin	40%	4	16,000
Paris	40%	1	4,000
Istanbul	40%	4	16,000
Lima	40%	2	8,000
Tehran	40%	3	6,000
Bangkok	25%	12	12,000
Chicago	50%	1	1,000
Bogota	0%	14	28,000
Hyderabad	35%	14	14,000
Chennai	35%	2	2,000

Essen	0%	1	1,000
Ho Chi Minh City	25%	1	2,000
Hangzhou	55%	2	2,000
Hong Kong	40%	2	2,000
Lahore	0%	2	2,000
Shenyang	0%	16	32,000
Changchun	40%	14	14,000
Bangalore	0%	2	8,000
Harbin	45%	1	1,000
Chengdu	70%	10	10,000
Santiago	0%	50	200,000
Guanzhou	20%	3	3,000
St. Petersburg	50%	1	1,000
Kinshasa	20%	4	4,000
Baghdad	20%	4	10,000
Jiana	40%	7	7,000
Houston	40%	14	14,000
Toronto	0%	25	100,000
Yangon	45%	1	1,000
Alger	60%	1	1,000
Philadelphia	35%	2	2,000
Qingdao	35%	1	1,000
Milano	35%	1	1,000
Pusan	30%	1	2,000
Belo Horizonte	25%	4	16,000
Almadabad	25%	6	24,000
Madrid	25%	8	32,000
San Francisco	25%	3	12,000
Alexandria	65%	1	1,000
Washington D.C.	25%	200	1,600,000
Wuhan	10%	34	136,000
Dallas	50%	1	1,000
Guadalajara	80%	1	1,000
Chongging	80%	1	1,000
Medellin	25%	3	6,000
Detroit	0%	1	1,000
Handan	25%	18	18,000
Frankfurt	45%	1	1,000

Porto Alegre	10%	3	6,000
Hanoi	15%	1	1,000
Sydney	40%	1	1,000
Santo Domingo	0%	8	8,000
Singapore	0%	1	1,000
Casablanca	50%	1	1,000
Katowice	25%	1	2,000
Pune	0%	1	1,000
Bangdung	30%	1	100
Monterrey	20%	2	2,000
Montreal	0%	1	1,000
Nagoya	0%	6	6,000
Nanjing	40%	6	12,000
Abidjan	40%	2	2,000
Xi'an	40%	2	2,000
Berlin	30%	24	24,000
Riyadh	50%	1	2,000
Recife	0%	1	1,000
Dusseldorf	45%	1	1,000
Ankara	25%	1	2,000
Melbourne	15%	1	1,000

Glossary

List of Constants and Variables

A – fixed setup (ordering) cost to produce (purchase) a lot (in dollars) (Hopp & Spearman, 2008)

c – unit production cost, not counting setup or inventory costs, of item (in dollars)

$\bar{d}$ – actual demand rate

d – calculated demand rate (units per unit time) for one or two indices

D – demand rate (in units per unit time) for three indices (x,y,z)

F – average lots per year

h – holding cost (in dollars per year), if holding cost consists entirely of interest on money tied up in inventory, then $h = i*c$

i – interest rate (%)

Q – lot size (in units)

w – modified probability used in calculations

$x \in X$ – set of all components $x \ \forall \ x = 1,2$

  - x_1 – power cells needed for a job
  - x_2 – inverters needed for a job

$y \in Y$ – set of all project $y \ \forall \ y = 1, \ldots, 91$

$z \in Z$ – set of all quarters $k \ \forall \ k =$ Q2 2012, … , Q4 2013

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Vita

Ian Christopher McFarland was born in Atlanta, Georgia. After graduating from Woodward Academy in College Park, Georgia in 2005, he began studies at Southern Methodist University in Dallas, Texas. In May 2010 he graduated with degrees of Bachelor of Science majoring in Mechanical Engineering and Bachelor of Arts majoring in French, along with a minor in Business. In September of 2009 he received his Diplôme de français professionnel B1 certification given by the Chambre de commerce et d'industrie de Paris and in August of 2010 he became registered as an Engineer in Training (EIT) with the Texas Board of Professional Engineers (License # 43957). In the fall of 2010, he began studies at The University of Texas at Austin towards a Masters of Science in Engineering majoring in Operations Research and Industrial Engineering. He has worked in quality control in the aviation industry and project management in the energy industry.

Permanent E-mail: Ian.McFarland@gmail.com

This report was typed by the author.