STRATEGIC FACILITY SITING IN A HIGHLY VARIABLE DEMAND ENVIRONMENT

by
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Submitted to the Sloan School of Management and
the Department of Civil and Environmental Engineering
in partial fulfillment of the requirements for the degrees of

Master of Business Administration
And
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in conjunction with the **Leaders for Manufacturing Program**
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Abstract

The hydrogen-powered fuel cell is a nascent product that holds great promise for becoming a disruptive technology in the power generation and transportation industries. However, significant technological hurdles remain to be overcome before the industry can achieve long-term growth, especially in the areas of powerplant efficiency, fuel cell stack life, and overall production costs. The dynamic forces created by sporadic technological advances, external market factors, and governmental incentives have produced a highly complex marketing environment where customer demand remains difficult to accurately forecast.

Operating within this highly uncertain demand environment, UTC Fuel Cells LLC has recognized the potential need to rapidly expand its production capacity if fuel cell demand even moderately exceeds forecasted levels. This project was developed to create a strategic roadmap that would allow the company to rapidly site a new production facility by rigorously identifying key decision parameters (facility location, size, timing, and cost) to optimize its chances of adequately meeting future market demand in the most cost-effective manner.

Key elements of the strategic roadmap include an existing facility capacity study, dynamic strategic planning site selection tools, and an automated freight cost model. These tools are combined into an HTML-enabled flowchart to provide a clear and concise methodology for amalgamating these elements into a cogent strategic framework.

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1. Introduction and Overview

Although the fuel cell industry has existed in some form for over 40 years, the nascent industry is only beginning to emerge from its traditional space-based market niche. The impetus for this sea change has primarily been driven by the advent of new technology that has allowed the use of lower cost materials. Consequently, for the first time in its history, the fuel cell industry has been able to propose cost competitive solutions for the assured power[*] generation market. In addition to the technological advances, the perceived acceleration of global warming and the very real threats of widespread power outages have only served to amplify the mounting societal pressure for environmentally friendly, renewable power sources.

Beckoned by this potentially lucrative business proposition, many companies have leaped into the fuel cell industry during the past decade. In addition to the many small startup companies that have been primarily funded by venture capital, several of the more prominent fuel cell companies have received significant financing from major players in the transportation and power generation industries. For example, Canada-based Ballard Power Systems launched a new venture in 1993 to develop a fuel cell-powered car by leveraging the considerable resources of Chrysler (now DaimlerChrysler). This venture was further bolstered by a $420 million cash infusion by Ford Motor Company in early 1998.[1] Other large corporations such as General Motors and Toyota have chosen to self-finance the product development process to ensure protection of their intellectual property and potentially gain first-mover advantage.

On many levels, the growing fuel cell industry closely resembles the personal computer (PC) industry during its formative years in the mid-1980s. Just as the inexpensive (but arguably inferior) PC architecture allowed many new companies to compete indirectly against entrenched mainframe computer manufacturers, the new and relatively inexpensive proton exchange membrane (PEM) fuel cell technology may prove to be a disruptive

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[*] Assured power generally refers to a specialized market segment that requires ultra-reliable electrical power to support critical functions. Typical customers include communication providers, hospitals, and financial institutions. Most assured power is currently provided by diesel-powered generators and/or battery backups.

technology in the transportation and power generation industries. Using the PC industry's historical growth as a bellwether, many observers are expecting the fuel cell industry to experience exponential growth, moving from $2.2 million to $2.4 billion in sales in less than four years.[2]

1.1 Statement of Problem

Although a general consensus exists for the fuel cell to play a major role in the future global economy, there remains considerable disagreement concerning the timing and true growth rate of the fuel cell industry. The dynamic forces created by sporadic technological advances, shifting competitive advantages, and expanding governmental incentives have produced a highly complex market environment where future product demand remains very difficult to forecast.

In the operations arena, the potential size of the fuel cell market in conjunction with the first-mover advantage have placed a premium on a fuel cell company's ability to rapidly expand its production capacity to meet almost any future product demand scenario. However, the highly uncertain market demand creates significant financial risks for the company as it attempt to properly size its production capacity; specifically, how much manufacturing capacity is enough to minimize lost sales due to capacity constraints while avoiding costly overcapitalization of manufacturing assets?

This operational planning dilemma requires a rigorous and risk-adjusted approach to strategic planning to ensure the long-term viability of the fuel cell manufacturer. By leveraging flexibility and risk mitigation in its capacity planning methodology, a fuel cell company can increase its market share while reducing its exposure to financial risks as it waits for the fuel cell market to mature.

1.2 Project Description

Operations at UTC Fuel Cells LLC (UTCFC) were significantly reorganized in 2001 to prepare the organization for a more streamlined manufacturing process that would permit maximum flexibility as product demand ramped-up for its next generation PC35™ commercial fuel cell. As the PC35 approached the final design stages, UTCFC embraced a new manufacturing concept that was a distinct departure from the job-shop type of manufacturing that it had pursued for over a decade while manufacturing the PC25™ commercial fuel cell in relatively low volumes.

To implement the new manufacturing concept, a new department was formed within UTCFC to oversee the consolidation of many smaller divisions. The new Vice President of Operations was tasked with creating a paradigm shift within the company that would emphasize lean manufacturing techniques and strategic partnerships with key suppliers. To enable this vision, all aspects of manufacturing the next generation fuel cell were placed under his auspices including supply chain design, manufacturing process design, facility planning, and procurement. A simplified diagram of the new organizational structure is shown in Figure 1-1.

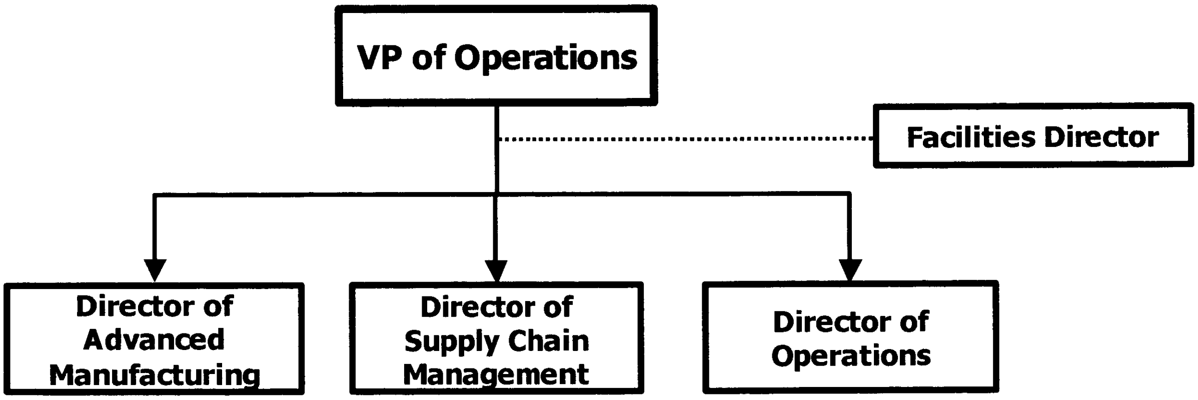

Figure 1-1: Operations Department Structure (partial)

Due to the limited manufacturing space available at the existing UTCFC site, it was readily apparent that a strategic planning process to expand production capacity would need to be rapidly developed to ensure the company could adequately meet the highly uncertain future product demand in a timely manner. This project was developed to address this need by developing a risk-adjusted strategic "roadmap" that would guide UTCFC's future manufacturing facility decision-making processes given any probabilistic-based product demand scenario. The goal of the project was to develop a long-term strategic plan that utilized rigorous analyses and risk-adjusted decision-making tools to permit the company to successfully navigate the highly uncertain future in the most cost-effective manner. In addition to providing a rigorous framework for decision-making, the strategic roadmap had to be flexible over time to guide the company's future production capacity decisions as more accurate product demand data became available. Finally, the strategic roadmap had to be clear, concise, and easy-to-navigate to ensure long-term use within the organization in spite of inevitable personnel changes.

1.3 Approach and Methodology

The relatively long lead times required to plan, locate, acquire, and populate a new facility (e.g. manufacturing space, office space, or warehouse) are generally applicable across all economic and industry sectors. Additionally, many companies must deal with at least some amount of uncertainty in their product demand forecasts. Consequently, many of this project's concepts and methodologies can be readily modified to meet the needs of numerous enterprises.

The initial step in the strategic facility planning process is to determine the maximum production capacity of the existing facilities (if applicable) and the expected timeframe during which the company will become capacity constrained given likely product demand scenarios. In this project, actual production of the PC35 commercial fuel cell had not yet begun, making maximum production capacity difficult to estimate. However, UTCFC had already developed a preliminary manufacturing production plan that roughly determined key variables such as production line sizing, manufacturing floorspace, and overall factory velocity. Using these variables along with UTCFC's best estimate of errors and assumptions, a Monte Carlo simulation was performed to "bracket" the existing facility's maximum production capacity. Although the maximum capacity estimates were only preliminary in nature, the Monte Carlo analysis also provided ample evidence that a significant bottleneck in inbound trucking traffic would occur well before the facility's maximum production capacity was reached. Using a Theory of Constraints analysis as developed by Goldratt[3]; an inbound traffic capacity study was completed using elements of queuing theory to accomplish the analysis. The study revealed that the existing facility was indeed capacity constrained by substandard loading dock access unless remedial actions were taken to alleviate the traffic constraints.

The second step in the strategic planning process is to use a rigorous analytical framework to determine the siting (location) of a new production facility assuming the existing facility is deemed unlikely to adequately meet future product demand scenarios. In this project, the concept of Dynamic Strategic Planning (DSP), an evolving field of decision analysis, was utilized to develop a risk-adjusted, flexible framework for new facility siting. DSP is a powerful decision-making tool that combines location-specific cost modeling with probabilistic product demand forecasts to generate a "best" solution for the facility location problem given the current accuracy of the demand forecasts. DSP is dynamic in that its solution can change over time as the cost models or demand forecasts become more accurate. This powerful tool allows senior management to make risk-mitigated, informed decisions for long lead time decisions (such as new facility acquisition) given current market uncertainties. In highly uncertain demand environments such as the fuel cell industry, DSP will enable UTCFC's senior management to make informed decisions concerning future facility siting and sizing. The key elements of the DSP tool are depicted in Figure 1-2.

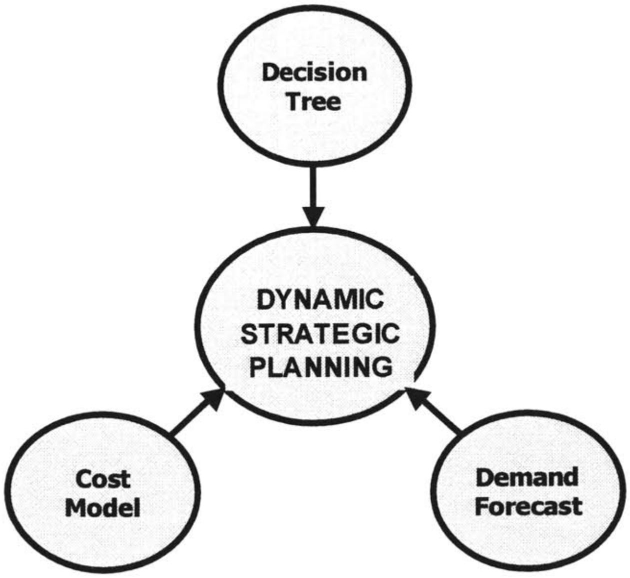

Figure 1-2: Elements of Dynamic Strategic Planning

The final step in the strategic planning process is to accurately identify company-specific operational cost drivers that are variable costs dependent on the production facility's location (site). These key cost drivers may include such factors as local labor rates, transportation costs, energy rates, real estate costs, and/or corporate tax rates. Since each company has a unique operational cost structure dependent on its product line, supplier network, and customer base, it must decide which operational costs are critical to its long-term success. Once these are identified, management should use these key operational cost drivers to screen and relatively rank each potential facility site before a final site is determined. Additionally, the key cost drivers may reveal the relative influence many major decisions such as manufacturing production design, product manufacturability, and supply chain design have on the final cost of goods sold. As an example of this analysis, inbound freight costs from a relatively fixed supplier base were determined to be the major operational cost driver for this project, a counterintuitive result that significantly shifted senior management's paradigms concerning UTCFC's future siting options.

The methodology outlined above has been synthesized into an HTML-enabled flowchart that provides detailed directions for stepping through the entire facility siting process. The computer-based, user-friendly format provides a clear visual "strategic roadmap" for future strategic planners to utilize as well as embedded decision-making tools in Microsoft Excel format.

1.4 Thesis Overview

This thesis is organized into five chapters:

> Chapter 2 provides background information concerning fuel cells, UTCFC, and the fuel cell industry. The chapter also provides general information about current facility siting methodologies based on a literature review.

Chapter 3 describes the facility siting methodology in detail. After determining the existing manufacturing facility's maximum production capacity, this chapter examines the use of DSP as a risk-mitigating decision tool in uncertain demand environments. Key elements of the DSP tool are described in this chapter, including detailed explanations of the freight cost and total operational cost models. Finally, this chapter investigates the implementation of the strategic roadmap for new facility siting, including the embedded DSP tool and HTML-enabled flowchart.

Chapter 4 investigates the initial implementation of the strategic roadmap by highlighting the results of the operational cost driver study. This chapter will also outline the recommendations made to the host company based on these preliminary findings.

Chapter 5 integrates the tools and findings from the previous chapters and provides recommendations given UTCFC's current situation. The final section outlines the strengths and weaknesses of the facility siting approach used in this project along with recommended areas for further study.

2. Background

2.1 The Fuel Cell

The hydrogen-powered fuel cell is an electrochemical device that converts fuel and air (oxygen) into electricity, heat, and water. Since the fuel cell uses only hydrogen and oxygen in an electrochemical process, it is a pollution-free method of generating electricity if a source of pure hydrogen is available. As an added benefit, the fuel cell generally operates at a higher efficiency than other power generation devices, allowing it to extract more latent energy from its fuel source. A simplified view of a proton exchange membrane (PEM) fuel cell is depicted in Figure 2-1.

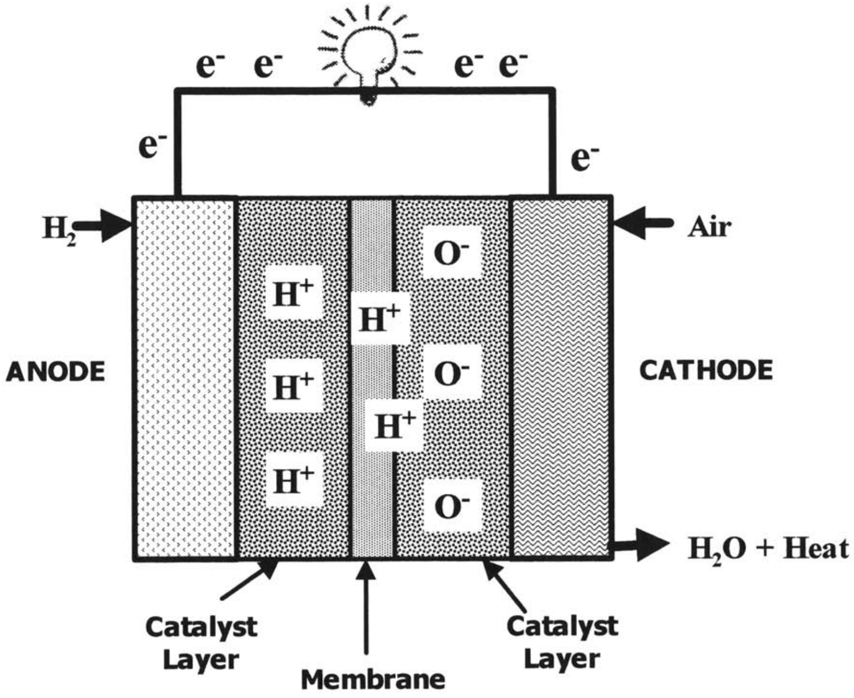

Figure 2-1: Simplified PEM Fuel Cell Diagram

The PEM fuel cell functions by supplying a hydrogen-rich gas (usually derived from natural gas or other hydrocarbon compound) to the anode side of the fuel cell while air is supplied to the cathode. A platinum-based catalyst layer strips the electrons from the hydrogen molecules, forcing the electrons to transit around the polymer membrane via an external circuit, providing electrical power to an attached load. Meanwhile, the specialized polymer membrane permits the protons (hydrogen ions) to pass through unimpeded, allowing them to recombine with the electrons and oxygen (from the air) in the fuel cell's cathode to produce pure water. The only other byproduct of this reaction is heat that can be partially reclaimed from the fuel cell's exhaust to increase the cell's overall efficiency.

PEM fuel cells are pollution-free devices only if pure hydrogen is used as the fuel source. However, the lack of a hydrogen-based fueling infrastructure currently dictates that commercially available fuel cells must use hydrocarbon-based fuels such as gasoline or natural gas as their source of hydrogen. This requires a relatively expensive reformation process that decreases the fuel cell's efficiency while simultaneously causing the emission of a small amount of polluting gases.

2.2 Company Background

UTC Fuel Cells LLC (UTCFC), formerly International Fuel Cells, is a Connecticut-based division of United Technologies Corporation (UTC), a $26 billion conglomerate centered on the defense and building product industries. UTCFC can trace its origins to the early 1960s when several UTC divisions were major players in the manned space flight programs. UTCFC's primary efforts centered on supplying alkaline-based fuel cells to the manned space flight initiatives, supporting both the Apollo and Space Shuttle programs. The Space Shuttle program continues to play a minor role at UTCFC in the form of overhauls, with over 107 supported missions and 84,000 hours of flight time.

Beginning in the mid-1980s, UTCFC leveraged its considerable expertise in the industry to develop a commercially-available fuel cell targeted for the assured power market. These large (200kW) fuel cells were designed to provide clean backup power to blackout-sensitive customers such as financial institutions, hospitals, and remote postal facilities. These efforts culminated in 1991 with the debut of the PC25™, a natural gas-powered fuel cell based on phosphoric acid technology. Although these units were relatively expensive compared to other sources of assured power such as diesel-powered generators and battery backups, they easily exceeded most technical specifications and effectively proved the concept of reliable energy production using environmentally friendly techniques. Since its debut, the PC25 has attained an installed base of over 220 units worldwide while successfully accumulating over 5 million hours of operation.

Since the early 1990s, proton exchange membrane (PEM) technology has come to the forefront of the fuel cell industry. Using relatively inexpensive and non-hazardous materials while operating at much lower temperatures, PEM-based fuel cells rapidly became the technology of choice in the transportation arena. Along with other major players in the industry, UTCFC entered developmental partnerships with five automobile manufacturers to develop fuel cell powerplants for future transportation applications. UTCFC's most prominent success to date was the widespread acclaim it garnered for a Hyundai Santa Fe SUV powered by a PEM fuel cell that debuted at the California Fuel Cell Partnership exhibition in November 2000. In addition to automobile powerplants, UTCFC has worked closely with several large commercial bus manufacturers to develop 75kW powerplants for the urban transportation market, a probable early adopter of fuel cell technology. UTCFC has also worked closely with BMW to develop a fuel cell-powered auxiliary power unit to provide sufficient electrical power to meet the needs of future high-end automobiles.

Concurrent with the transportation R&D programs, UTCFC has been leveraging its expertise in PEM-based fuel cells to develop the next generation commercial power unit, the PC35™. This PEM-based 150kW commercial unit is expected to replace the PC25 in the next several years, leveraging lower cost materials and better production techniques to provide large-scale assured power at a more competitive price. UTCFC believes that this product will rapidly gain widespread success, leading to profitability for the company for the first time in its history. By becoming a profit center, the company is hoping to shed its image as strictly an R&D organization while becoming a major revenue producer within the UTC family of companies.

2.3 Fuel Cell Industry Background

Since the late 1990s, the fuel cell industry has experienced a massive increase in research and development efforts with over $1 billion being expended on an annual basis.[4] A recent study conducted by a non-profit industry council noted that there are over 850 companies and organizations developing fuel cells or performing basic research functions, each hoping to tap into an estimated $20 billion in annual sales by the end of the decade.[5]

2.3.1 Fuel Cell Technologies

There are four fuel cell technologies that have emerged over the past thirty years that hold the most promise for future applications. The most mature of these technologies is the phosphoric acid fuel cell (PAFC) that emerged during the 1970s. This technology proved very reliable and became the first fuel cell technology to be commercially offered to the general public in 1991. PEM fuel cell technology rapidly emerged on the scene in the early 1990s as R&D efforts discovered new methods for reducing the precious metal content (platinum) of the fuel cells. With reduced raw material costs and generally lower operating temperatures, many fuel cell companies wishing to enter the transportation and residential markets rapidly adopted the PEM technology.

Looking further into the future, there are currently two advanced fuel cell technologies that hold even greater promise for increased power density and powerplant efficiency.[*] Operating at significantly elevated temperatures, molten carbonate fuel cells (MCFC) have higher efficiency ratings (45-55%) but still face significant technological hurdles in the area of cell stack life. Similar to MCFCs, solid oxide fuel cells (SOFC) also operate at extremely high temperatures and have been experimentally shown to have long cell stack lives with only limited degradation. Based on these promising preliminary results, SOFC technology holds the greatest promise for large-scale market penetration. Several U.S. Department of Energy (DOE) programs are currently funding additional research into these technologies, hoping to integrate a high-temperature fuel cell with co-generation plant capabilities to further increase powerplant efficiency. The DOE's current long-range strategy is depicted in Figure 2-2.

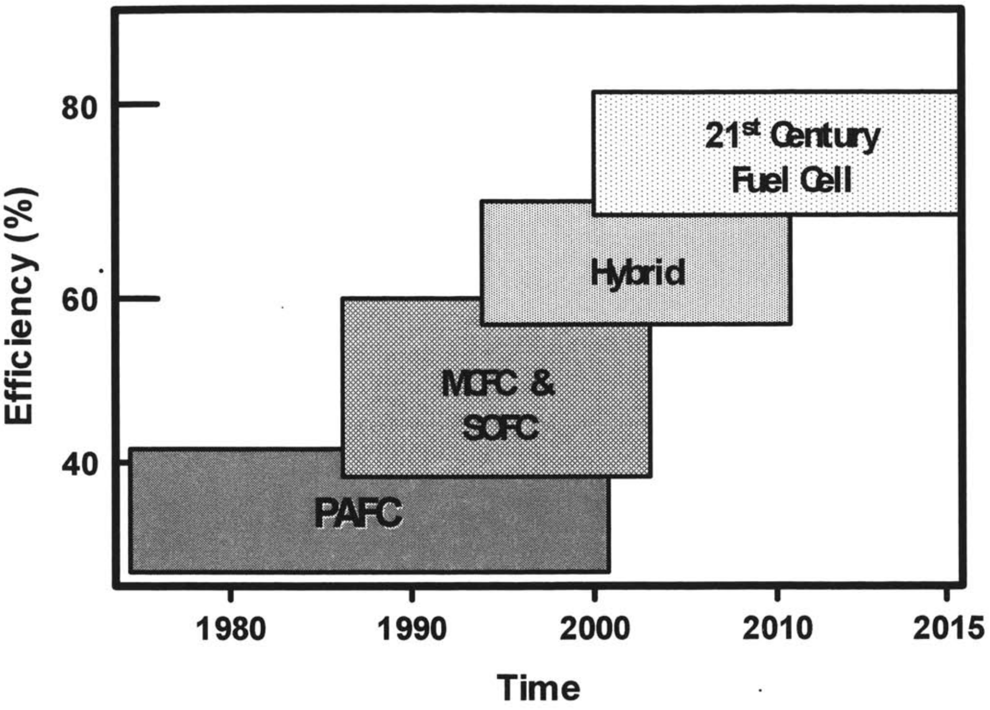

Figure 2-2: DOE Future Fuel Cell Strategy[8]

2.3.2 Fuel Cell Industry Competitive Landscape

As the world's only commercially-available PAFC is being phased out at UTCFC, the relatively inexpensive PEM technology has attracted a significant number of new companies to the industry. The major vendors investing in this new technology include UTCFC, Ballard Power Systems of Burnaby, BC, GE-backed Plug Power of Latham, NY and H-Power of Clifton, NJ. In addition to these larger companies, there are over 30 companies developing PEM fuel cell technology on a worldwide basis.[6]

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[*] For this discussion, efficiency is defined as the percentage of useable energy the technology can extract from the fuel's total available heating energy. For comparison purposes, a gasoline-powered internal combustion engine is approximately 20% efficient.

In the high temperature fuel cell arena, Fuel Cell Energy of Danbury, CT is the leading MCFC developer with several 250kW units undergoing field-testing. Siemens Westinghouse has been the leading SOFC developer with plans to commercialize SOFC co-generation systems by late 2004.[7]

2.4 Facility Siting Methodology Overview

A high-level review of academic research reveals a plethora of studies analyzing supply chain optimization and factory floor design. However, the same review reveals a relatively smaller amount of literature dedicated to strategic facility siting although this is a long-term, capital-intensive decision made by all growing companies.

On an anecdotal level, many seemingly successful companies are rife with stories about how their existing facilities were sited. Although many of these companies may have initially attempted to perform a rigorous and analytical approach to their siting decisions, the lack of a standardized siting decision framework may have led more than one company to locate its new facility near a former CEO's favorite vacation destination. For some risk-adverse companies, their new facility may have been sited next to their existing facility with little consideration given to finding an optimal location that would extend the business' competitive advantages.

2.4.1 Facility Siting Literature Review

The first appearance of a formal facility-siting framework occurred in 1909 when Alfred Weber tackled a warehouse location problem to minimize distance traveled.[9] From that date forward, a large body of literature has emerged to extrapolate on Weber's initial insights, with the majority occurring after the advent of the digital computer in the mid-1960s.

In the early 1960s, Hakimi[10] published a seminal paper that described the mathematical foundations for finding the proper location of a telephone switching station to minimize the total demand-weighted travel distance. This paper was the origin of the *p*-

median location problem, an insight that formed the basis for static and deterministic facility siting problems for the next 40 years. These types of problems used constant, well-known inputs to determine an optimal solution at only a single point in time.

Many variations of the static/deterministic type of facility siting model were published during the next several decades. Unfortunately, these algorithms were normally modeled by enumerating all the possible solutions, making them computationally difficult to solve. Compounding the problem, only a few business organizations had the organic knowledge and computational capability to leverage these models, creating a heavy reliance on heuristically-determined rules of thumb to guide their new facility siting decisions.

By the late 1960s, a body of literature emerged which expanded the traditional p-median problem. In this research, a fixed cost was added to the p-median objective function to obtain a more accurate representation of the total cost for siting a facility at a given location. This *uncapacitated fixed cost location* methodology endogenously determined the minimum total cost of operating a facility (construction plus distance considerations), thus providing strategic planners with another level of granularity during their decision-making process.[11] Although this refinement was a welcomed addition to the body of knowledge, it still suffered from the same drawbacks of static/deterministic models since it did not capture many of the real-world nuances facing strategic planners. Additionally, these modeling techniques did not address the aspect of future uncertainty since all inputs were assumed to be known and constant over time.

In 1968, Ballou[12] published an influential paper on warehouse location strategies that outlined the limitations of the static/deterministic modeling techniques. This work, which was later amplified by other researchers, formed a new body of research that was later dubbed *dynamic modeling*. By definition, dynamic modeling incorporated time; specifically, Ballou's followers argued that facility siting problem formulations should not be limited to constant input values but rather should be allowed to change to reflect real-world conditions. Consequently, the inputs for these models took on a stochastic nature, using either *probabilistic* or *scenario-based* approaches. The inputs to the probabilistic-based approach varied according to a probability distribution function (PDF), usually derived from a regression of real-world data. The scenario-based approach attempted to capture uncertainty by specifying a limited number of possible future planning states. The objective of this type of model was to identify a solution that performs best under all given situations.

Dynamic modeling concepts began to expand in the early 1970s with a paper by Sheppard[13] that took the modeling beyond simple facility location problems and extended the concept to other real-world issues such as appropriate facility sizing and acquisition timing. Unfortunately, Sheppard's problem formulations were nonlinear and dynamic in nature, making them nearly impossible to solve in a computational manner.[14] Consequently, many researchers turned to other modeling techniques, such as a relaxation of the constraints and using deterministic inputs to solve the problem in a heuristic manner. Using these simplifications, researchers were able to generate near-optimal solutions that were more than adequate to meet the needs of businesses looking to optimize their operations.

The increasing computational power available to researchers by the early 1990s allowed a greater incorporation of probabilistic-based inputs into the facility location optimization models. An example of this trend is evident in the work performed by Bean et al.[15] when they used an equivalent deterministic demand formula to simulate a stochastic demand forecast.[16] Another relevant issue that has taken facility sizing to the next logical step is the probabilistic availability of the facility to service its customers at any given point of time.[17] Much of this research has been centered on using queuing theory to analyze these average service time problems.

2.4.2 Evolution of Facility Siting Decision Methodologies

Although the operations research (OR) community made great strides in helping business practitioners understand and optimize their enterprises, many of their system optimization techniques saw limited success when they were applied to real-world challenges as part of larger corporate strategic plans.

While there are many reasons for these failures, de Neufville states, "a large number of them are attributable to the fact that the analyses have either not incorporated risks and uncertainty into the process, or have failed to create plans with the flexibility to respond to these risks as they occurred."[18] Additionally, most OR techniques assume that the systems they are optimizing are well understood so that key inputs and parameters can easily be entered into the optimization model. Although this assumption works well for tactical management decisions that are characteristically near-term in nature, it is generally not appropriate for the strategic planning process where many of the parameters change unpredictably over time.

The realization that system optimization techniques were somewhat limited in their strategic value prompted the rise of *decision analysis* frameworks during the 1980s. Decision analysis techniques attempt to mitigate the shortcomings of system optimization techniques by incorporating risk and uncertainty into the strategic decision-making process. By providing a rigorous and systematic way of incorporating risk into the process, decision analysis permits strategic planners to find an optimal long-term policy among many possible alternatives, considering the risks they may encounter in such areas as future product demand and disruptive technology. Unfortunately, decision analysis techniques are also hampered by several major drawbacks that are outlined below:[19]

- Even simple decision analysis frameworks generate many possible future outcomes since each permutation (risk) must be enumerated to find the optimal solution. Modeling these permutations can be extremely time intensive and costly, making even modestly-sized decision analyses difficult to accomplish.
- The model designer must be able to identify and understand each possible alternative during the initial modeling phase to properly model the cost and risks associated with each permutation. Due to future uncertainties and incomplete knowledge of the subject matter, this can be difficult to accomplish.
- Strategic plans inevitably change over time as the major stakeholders involved have changing priorities and perspectives during the time period analyzed.

In the last two decades, significant strides in computational methodologies and power have provided some degree of success for decision analysis techniques. However, the considerable time, effort and knowledge required to effectively apply these techniques to complex real-world systems has yielded only limited results.

Dynamic strategic planning (DSP) is a recently developed methodology for designing complex strategic plans in uncertain business environments. Firmly based on the success of earlier decision analysis techniques, DSP attempts to leverage the rigorous analysis methodologies outlined above with the real option theories that have transformed the financial stock markets. DSP develops a risk-adjusted strategic plan that is flexible over time, allowing key decisions such as facility siting to be completed one step at a time while allowing the plan to adequately adjust to future changes in product demand, technological improvements, or the competitive environment.[20] DSP has been compared "…to playing chess: the planner thinks many moves ahead, but only commits to one move at a time, retaining the flexibility to adjust the game plan according to the events as they unfold."[21] Some of the key advantages of the DSP methodology include:

- Flexibility in future planning. Using financial stock options as an analogy, DSP takes advantage of the opportunity to "buy" in a future good situation (calls) and the option to "sell" in a bad situation (puts).
- Provides a rigorous strategic planning framework for decision-making in an uncertain environment. DSP effectively leverages decision analysis and OR tools to make the "best" initial decision given uncertain information (risk).
- Outlines a plan that gives a decision maker a set of guidelines concerning **what** decision to make, **how** it should be accomplished, and **when** to implement the plan.

Although DSP has primarily been used to date as a planning tool for large civil or energy-related projects, the remainder of this project will demonstrate how the DSP framework can be effectively leveraged in the corporate sphere to develop rigorous, risk-mitigated strategic plans while operating in a highly uncertain environment. Specifically, this project demonstrates how DSP will be used at UTCFC to site a new manufacturing facility in the face of highly uncertain product demand forecasts.

3. STRATEGIC FACILITY SITING

3.1 Introduction

Long-term capital expenditure decisions are one of the most intractable problems that business managers must face on a routine basis. In the new facility siting process, uncertain future product demand and significant amounts of required capital make the decision process especially difficult while potentially affecting the future careers prospects of all the managers involved. Surprisingly, many of these major facility-siting decisions are made with little or no rigor in the decision-making process, providing scant support for the key decision makers in the future if the new site does not develop according to their original plans.

Another major strategic planning hurdle facing managers is the inherent long-term nature of facility siting decisions. Key issues such as manufacturing system design, IT implementation, and capital structuring are by nature long-term evolutions that take considerable time and forethought to successfully accomplish. During this long decision-making process, some managers will inherently rotate through the strategic planning effort due to regular personnel shifts within a corporation. This rotation of personnel leads to a lack of cohesiveness within the team since each new member must become familiar with the general strategic planning process before becoming a contributing member. Additionally, the strategic planning project may lack an overall sense of direction since many of the key planning personnel will not be present for the entire strategic planning process from start to finish.

Finally, although many of the managers currently involved in the planning project may be familiar with the new facility strategic planning process, there usually is little forethought invested in concisely recording and saving their facility siting methodology for future managers to emulate as future capacity needs dictate.

3.2 Facility Siting Strategic Roadmap

UTCFC's Operations Department was facing the difficult task of planning future production capacity given a highly uncertain product demand. Although there was a general consensus among many industry analysts that fuel cell demand would quickly become exponential in nature once key cost hurdles were surmounted, there were also many external factors such as the future energy costs (e.g. worldwide oil prices) and governmental incentive programs that were difficult to predict. Consequently, UTCFC's operations managers were faced with a dilemma; namely, should they expand production capacity now in anticipation of exponential product demand or wait to get better demand data and risk lost sales? This capacity-planning dilemma is illustrated in Figure 3-1.

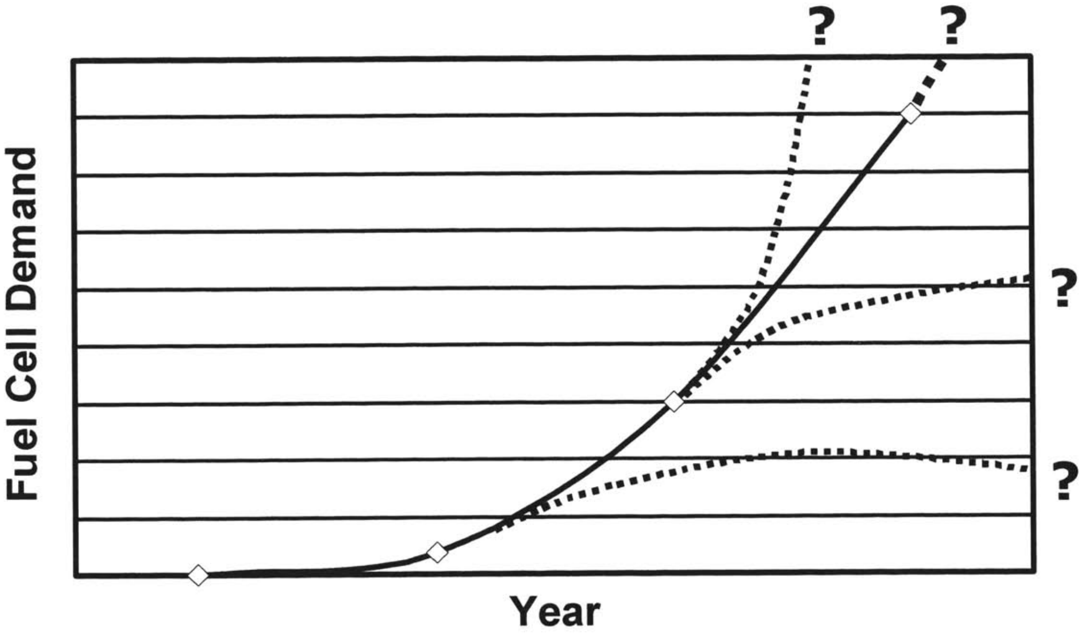


Figure 3-1: Fuel Cell Capacity Planning Dilemma

With the pending production start of the PC35 commercial fuel cell and a future planned introduction of a residential fuel cell, managers realized they needed a long-term strategic plan that employed flexible methodologies that could rapidly change to meet future product demand scenarios. This pressing need was the impetus for sponsoring the LFM internship that eventually led to the creation of the High Volume Facility Strategic Roadmap.

The High Volume Facility Strategic Roadmap was designed to provide senior managers with a clear and concise strategic methodology for acquiring a new high volume manufacturing facility to adequately meet expected customer demand in a rapidly-changing (exponential) growth environment. The key strategic goals of the roadmap were:

- Provide a concise, HTML-enabled flowchart that visually represented a clear strategic plan for acquiring a new manufacturing facility. This flowchart would also provide continuity for the strategic planning team during personnel changes while concurrently documenting the procedure for future planning efforts.
- Provide a rigorous framework for decision-making by employing risk-adjusted decision analysis tools such as dynamic strategic planning, cost modeling, and queuing theory.
- Shorten deployment time and increase usability by providing HTML-enabled instructions embedded in the flowchart that utilized user-friendly hyperlinks to pertinent data sources and tools.

To meet the project goals outlined above, the strategic roadmap was designed to act as a sequencing document that provided a clear timeline of how the planning process should unfold. To ensure an orderly and manageable planning process, the roadmap was divided into four distinct phases. The end of each phase was marked by a "milestone," a natural stopping point in the planning process that allowed senior management and the strategic planning team to regroup and survey the future planning horizon. The general meeting marked by the milestones also ensured senior management was fully briefed on the strategic planning group's conclusions determined during the preceding phase. The milestone meetings then acted as a major decision point for the company with the end result being either to suspend the site selection process or move forward into the next phase. This decision was based on the current information (e.g. cost estimates, potential sites) gleaned during the site selection process and the anticipated future production needs of the company.

The phased site selection approach provided significant flexibility to the planning process since accurate information obtained at a later date could be used to modify the company's production capacity plans.

A general outline of the phases contained in the High Volume Facility Strategic Roadmap is depicted in Figure 3-2.

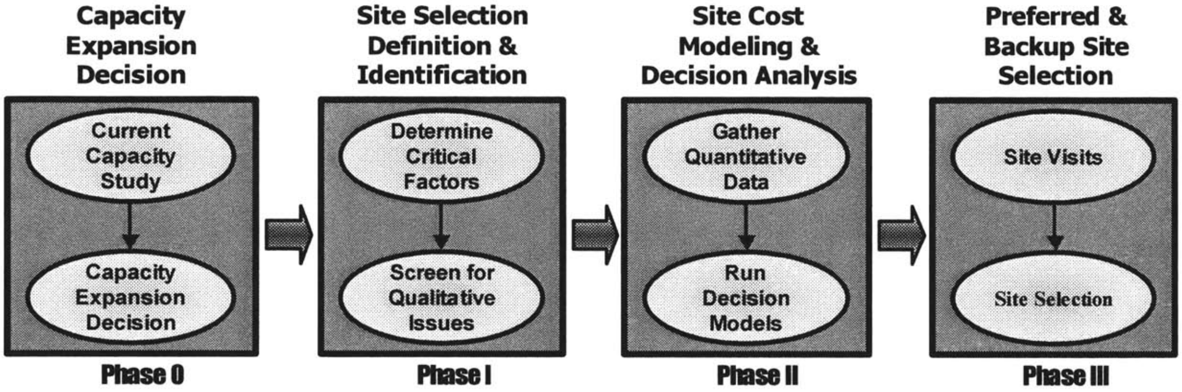


Figure 3-2: Strategic Roadmap Overview

Based on the outline presented in Figure 3-2, a detailed version of the High Volume Strategic Roadmap is shown in Figure 3-3 with the key elements explained in the following section.

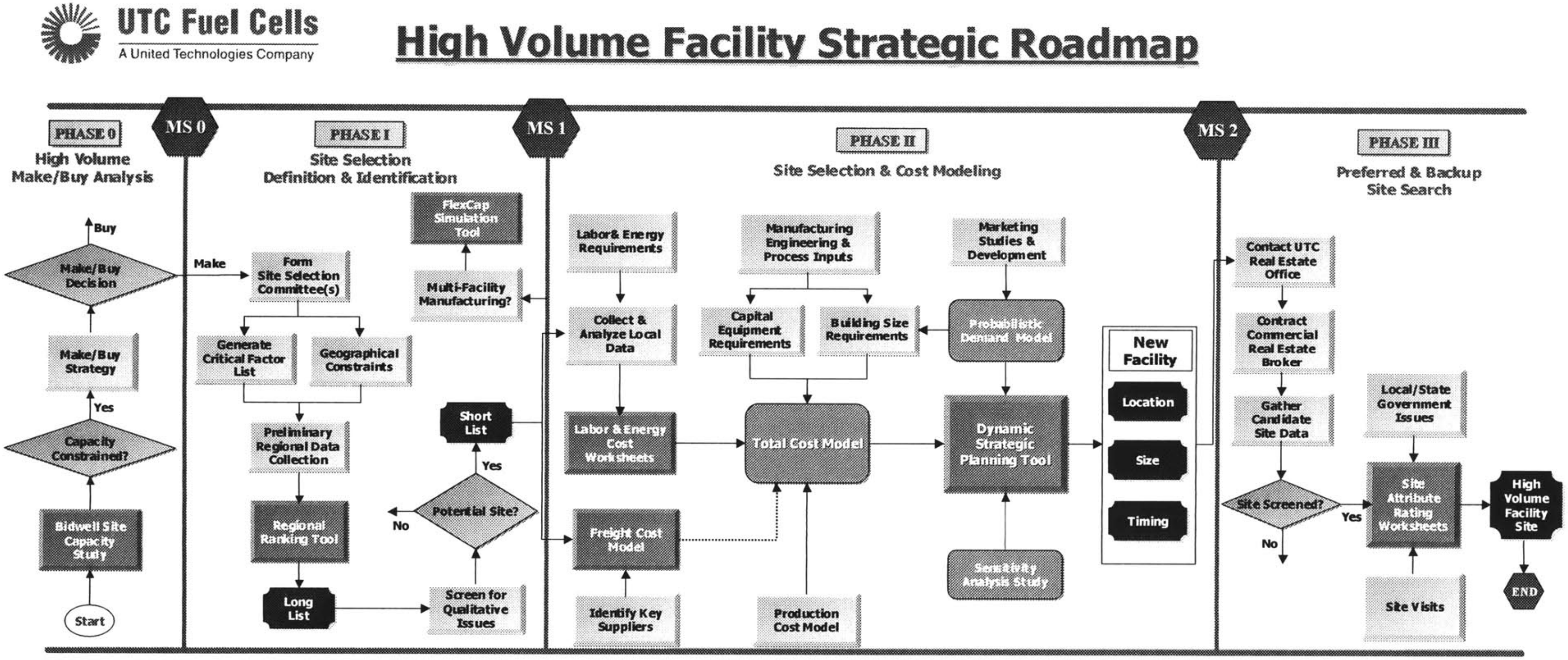


Figure 3-3: High Volume Facility Strategic Roadmap

3.2.1 Strategic Roadmap Elements

Although the High Volume Facility Strategic Roadmap (Figure 3-3) was tailored to meet UTCFC's specific needs, the concepts and methodologies employed by the roadmap can be readily adapted to meet the strategic facility planning requirements of many manufacturing organizations. Some of the key principles and methodologies employed in the roadmap are highlighted below.

Phased Approach with Milestones

As outlined above, the new facility siting decision-making process is divided into four distinct phases, each separated by a decision milestone. The purpose of the milestones is to provide senior management with a built-in process halting mechanism to allow for adequate reflection on the key findings of the previous phase and to develop a clear consensus for further facility acquisition efforts. Additionally, the milestones allow the strategic planning team to work unfettered during each planning phase while ensuring senior management's inclusion and "buy-in" once the phase is completed.

HTML-Enabled Instructions

To facilitate ease-of-use and higher adoption rates by end users, the entire roadmap has been divided into three HTML-enabled screens that work with any web browser. The first two phases of the HTML-enabled roadmap are shown in Figure 3-4.

Each descriptive text box on the flowchart acts as a "button" when clicked by the user's cursor, hyperlinking to underlying text-based screens that provide specific instructions to the end user. Additional hyperlinks are included in the instructional text to allow the user to rapidly access data from other parts of the roadmap or open Excel-based decision-making tools. A sample screenshot of the Dynamic Strategic Planning Tool's instruction page is shown in Figure 3-5.

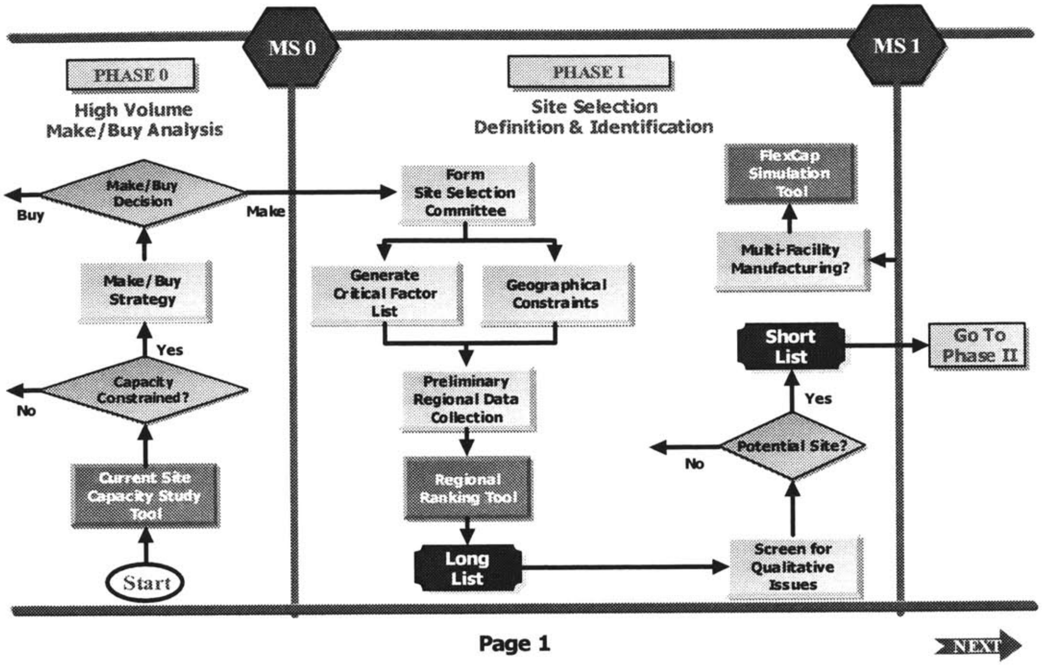
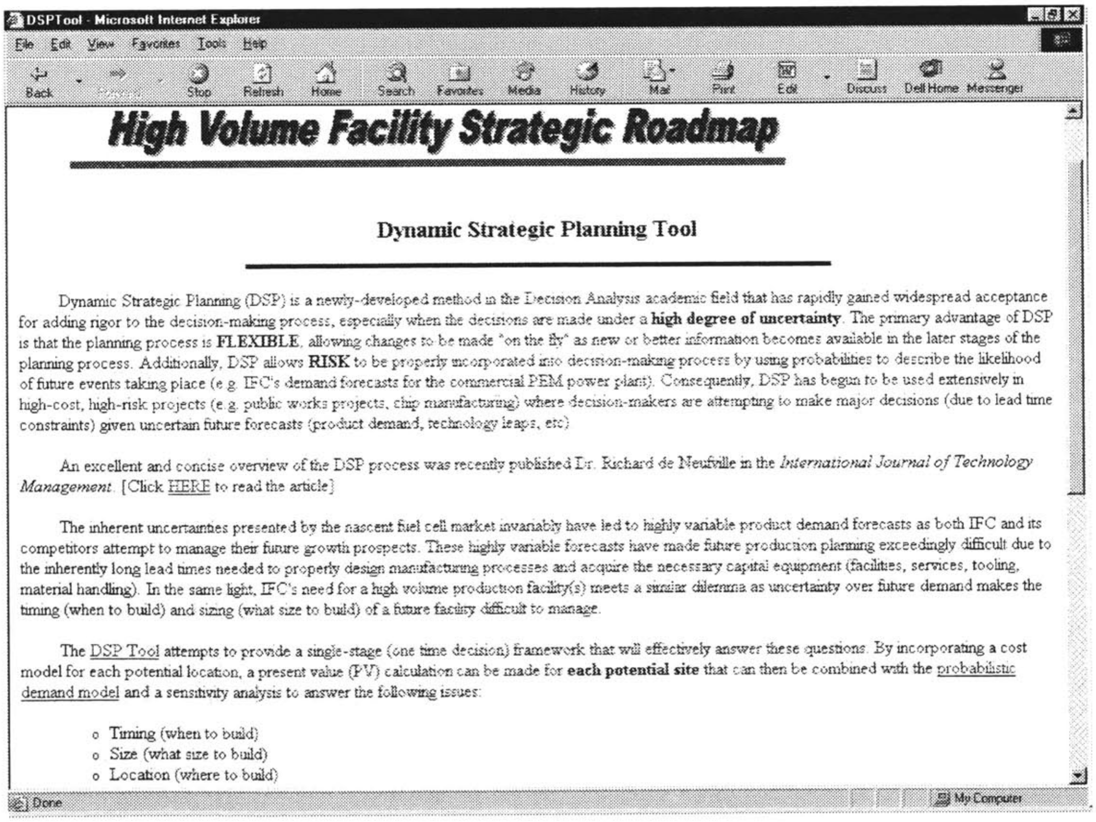


Figure 3-4: First Page of HTML-Enabled Roadmap



High Volume Facility Strategic Roadmap

Dynamic Strategic Planning Tool

Dynamic Strategic Planning (DSP) is a newly-developed method in the Decision Analysis academic field that has rapidly gained widespread acceptance for adding rigor to the decision-making process, especially when the decisions are made under a **high degree of uncertainty**. The primary advantage of DSP is that the planning process is **FLEXIBLE**, allowing changes to be made "on the fly" as new or better information becomes available in the later stages of the planning process. Additionally, DSP allows **RISK** to be properly incorporated into decision-making process by using probabilities to describe the likelihood of future events taking place (e.g. IFC's demand forecasts for the commercial PEM power plant). Consequently, DSP has begun to be used extensively in high-cost, high-risk projects (e.g. public works projects, chip manufacturing) where decision-makers are attempting to make major decisions (due to lead time constraints) given uncertain future forecasts (product demand, technology leaps, etc)

An excellent and concise overview of the DSP process was recently published Dr. Richard de Neufville in the *International Journal of Technology Management*. [Click HERE to read the article]

The inherent uncertainties presented by the nascent fuel cell market invariably have led to highly variable product demand forecasts as both IFC and its competitors attempt to manage their future growth prospects. These highly variable forecasts have made future production planning exceedingly difficult due to the inherently long lead times needed to properly design manufacturing processes and acquire the necessary capital equipment (facilities, services, tooling, material handling). In the same light, IFC's need for a high volume production facility(s) meets a similar dilemma as uncertainty over future demand makes the timing (when to build) and sizing (what size to build) of a future facility difficult to manage.

The DSP Tool attempts to provide a single-stage (one time decision) framework that will effectively answer these questions. By incorporating a cost model for each potential location, a present value (PV) calculation can be made for **each potential site** that can then be combined with the probabilistic demand model and a sensitivity analysis to answer the following issues:

- Timing (when to build)
- Size (what size to build)
- Location (where to build)

Figure 3-5: Screenshot of DSP Tool Instruction Page

Decision-Making Toolset

The centerpiece of the strategic roadmap is a highly-customized DSP tool using Microsoft Excel to encourage widespread adoptability by end users. Key elements of the DSP tool include a total operational cost model, a probabilistic demand model, and a sensitivity analysis study. Major elements feeding the cost model include a highly automated, UTC-specific freight cost model (inbound and outbound) as well as local labor and energy cost worksheets.

Qualitative Site Screening

Several tools are embedded into the strategic roadmap to facilitate the screening of quantitatively-generated results using **qualitative** metrics (e.g. cultural fit) as well as general quality of life factors such as local recreation and educational facilities. MacCormack, Newman, and Rosenfield[22] highlighted the increasing need to incorporate qualitative aspects in the decision-making process since they are emerging as key facility siting factors in the increasingly global manufacturing environment. They argue that the overall success of widely-used production methodologies such as just-in-time (JIT) manufacturing and flexible manufacturing systems hinge on a highly skilled, motivated labor force that is an integral part of the company's overall business strategy.

3.3 Existing Facility Capacity Study

The High Volume Facility Strategic Roadmap provides an excellent overview of the various tools and methodologies employed during the new site selection process. This section will explore the mechanics of a few of these tools to explain in greater detail how the facility siting methodology functions.

As a note of caution, the methodologies outlined in this project are specific to the needs of UTCFC. During this time period, the final design of the PC35 commercial fuel cell had not been completed with actual production ramp-up scheduled to occur no earlier than late 2002. Consequently, the reader should note that some of the tools and methodologies employed during the project were matched with the uncertainties present at the time of the internship.

3.3.1 Determining Maximum Plant Throughput

The first key question that must be rigorously examined when siting a new production facility is when should the new facility be operational? The answer to this question is crucial since it drives the entire facility siting process, acting as the trigger to implement the processes outlined in the strategic roadmap.

The difficulty in answering this question varies significantly between manufacturing enterprises. For companies that are already producing near maximum capacity with little room to spare for additional production, the answer is quite simple—now! However, this question poses significant problems for companies facing highly uncertain product demands. In the case of UTCFC, this question poses an even bigger dilemma since volume production had not commenced.

Although volume production of the PC35 had yet to occur at UTCFC's South Windsor site, a significant amount of manufacturing engineering work had been completed in anticipation of the unit's ramp-up, generating a fairly detailed production plan. This plan outlined key production variables such as production floorspace, assembly sequencing, assembly time per station, finished product testing time, and overall factory velocity. Additionally, the experience gained during the production planning effort enabled UTCFC's manufacturing engineers to acquire a general estimate for the variability each process was likely to encounter once actual production commenced.

With expectations of exponential product demand growth and only limited amounts of available manufacturing floorspace, a rough estimate of the existing facility's maximum throughput was needed to generally predict when a new manufacturing facility would be needed to adequately meet forecasted demand. Since actual production numbers were not yet available, a Monte Carlo simulation using Palisade Software's @Risk™ analysis tool was conducted using values from the preliminary production plan along with variance estimates supplied by the manufacturing engineers. Key variables used in this Monte Carlo simulation included:

- Estimated area of a single assembly line (ft^2)
- Estimated area of a finished product test stand (ft^2)
- Estimated days of on-site inventory (used to estimate laydown area size)
- Estimated assembly time (minutes per station)
- Estimated finished product testing time (minutes)

Using known parameters such as total production floorspace, an Excel spreadsheet was designed that estimated the annual throughput of the PC35 production facility given projected variances in the above parameters. The general goal of the analysis was to estimate the lower and upper bounds of the annual throughput that could then be compared against current product demand forecasts to determine a general timeframe when a new production facility would be required. To run the Monte Carlo simulation, each variable was given an appropriate distribution (normal, triangular, uniform) and values (including upper and lower bounds) that reflected the manufacturing engineers' current best estimates since the production line design was still in the developmental stages.

Although only preliminary in nature, the study revealed that the current facility could meet forecasted demand for the next several years. A sensitivity analysis was also performed by the @Risk™ software package to reveal which production variables were the key drivers in determining the facility's maximum annual throughput. A sample output graph from a Monte Carlo simulation run is shown in Figure 3-6.

A summary of the key findings of the existing facility throughput study using Monte Carlo simulation are outlined below:

- Existing facility throughput was highly dependent on product assembly time. This finding was a secondary effect driven by the discrete nature of assembly lines where only a few (relatively large) assembly lines could be physically located within the given confines of the production floorspace.

- Testing time variation for finished units was not an important throughput driver, contrary to earlier assumptions. This finding was primarily driven by the relative physical size difference between a test stand and an assembly line, making additional test stands easier to place within the confines of the given production floorspace.
- Based on the above results, UTCFC should concentrate their manufacturing engineering resources on assembly process improvements to lower assembly times at each station since this was identified as the major throughput driver that could be significantly changed over time. Lower assembly times would significantly increase annual throughput, effectively "buying" additional time for UTCFC to accurately assess the uncertain fuel cell market demand.
- The study revealed that UTCFC would outgrow their existing facility within a few years if product demand forecasts proved to be even moderately accurate. Consequently, a new site selection process was required to begin within a relatively short timeframe due to the long lead times required for the process.

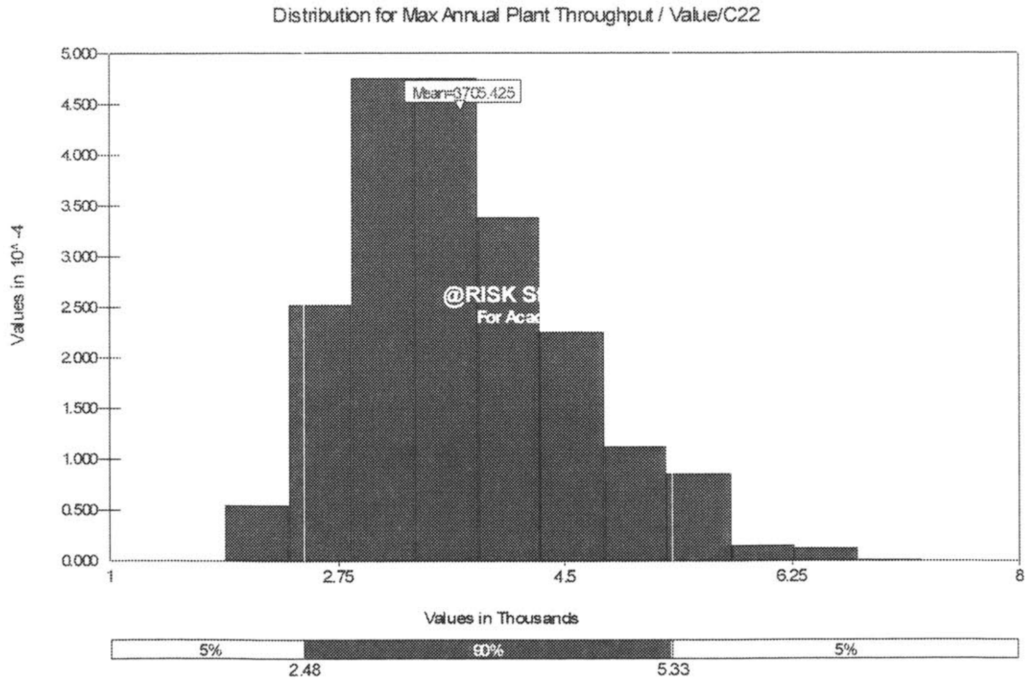


Figure 3-6: Sample Run from Monte Carlo Simulation

3.3.2 Theory of Constraints Analysis for Truck Loading Docks

Once the maximum annual throughput simulation was completed, a theory of constraints (TOC) analysis was performed on the existing facility to determine if the truck loading docks were a bottleneck that would artificially limit the current site's maximum throughput.[23]

The driving impetus behind the TOC analysis was an unproven insight that the current facility's unusual physical configuration would significantly restrict inbound material (subassembly) flow, effectively starving the assembly lines. Specifically, the facility's unusual truck loading dock configuration and limited road access allowed only a small number of tractor-trailers to be unloaded at any given time. This bottleneck could place significant constraints on the facility's throughput since the newly-created supply chain design dictated a just-in-time (JIT) delivery scheme from strategic subassembly suppliers. In the JIT delivery scheme, tractor-trailers were expected to randomly arrive on a given day from major suppliers located throughout the country since the existing facility's on-site storage capacity was severely limited.

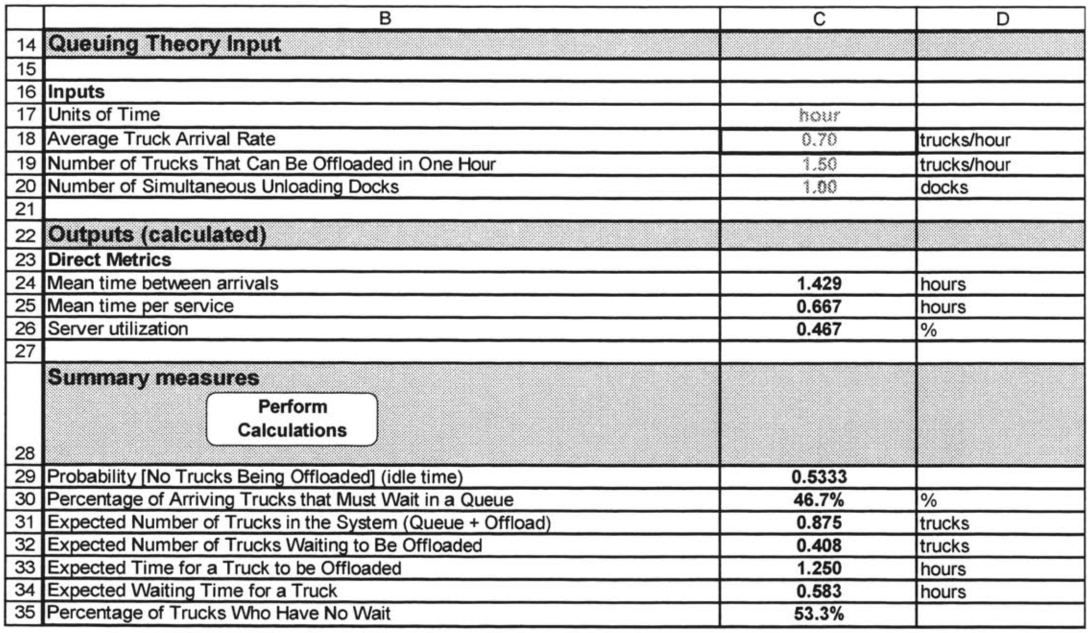
Based on the expected daily random arrival pattern (Poisson) of inbound trucks, a loading dock capacity analysis was performed using queuing theory as the basis of the study. The purpose of the analysis was to determine the maximum number of PC35 units that could be manufactured on an annual basis given a JIT inbound delivery scheme and the physical constraints of the existing facility. Key inputs for the queuing analysis were determined by performing a one-week study of current inbound deliveries. The short-term study provided realistic values for the following variables:

- Average truck maneuvering time
- Average truck unloading time (by van size)
- Loading dock truck constraints (some docks could not handle large truck sizes)

- Forklift traffic constraints
- Available subassembly storage space

A feasibility and cost analysis of potential site improvements was also conducted in conjunction with the Facilities Department to determine if minor changes to the site could increase the number of available loading docks.

Using the data collected during the study, the queuing analysis was conducted assuming Poisson-distributed truck arrival rates. A generic Visual Basic-based subroutine[24] was modified to serve as the queuing theory calculation engine underlying an Excel spreadsheet interface. Figure 3-7 shows a sample of the Excel interface for inputting data and determining average truck waiting times.



	B	C	D
14	**Queuing Theory Input**		
15			
16	**Inputs**		
17	Units of Time	hour	
18	Average Truck Arrival Rate	0.70	trucks/hour
19	Number of Trucks That Can Be Offloaded in One Hour	1.50	trucks/hour
20	Number of Simultaneous Unloading Docks	1.00	docks
21			
22	**Outputs (calculated)**		
23	**Direct Metrics**		
24	Mean time between arrivals	**1.429**	hours
25	Mean time per service	**0.667**	hours
26	Server utilization	**0.467**	%
27			
28	**Summary measures**		
29	Probability [No Trucks Being Offloaded] (idle time)	**0.5333**	
30	Percentage of Arriving Trucks that Must Wait in a Queue	**46.7%**	%
31	Expected Number of Trucks in the System (Queue + Offload)	**0.875**	trucks
32	Expected Number of Trucks Waiting to Be Offloaded	**0.408**	trucks
33	Expected Time for a Truck to be Offloaded	**1.250**	hours
34	Expected Waiting Time for a Truck	**0.583**	hours
35	Percentage of Trucks Who Have No Wait	**53.3%**	

Figure 3-7: Queuing Theory Calculator Interface

While conducting the study, a major site traffic constraint was determined to be the limited amount of space available to park idling trucks if they had to wait for the next available loading dock. Due to the site's physical configuration, these trucks were forced to park on the narrow site access road, creating a potential traffic bottleneck for other inbound and outbound trucks. Consequently, it was subjectively determined that a truck should have to wait no more than 50% of the time (on average) for an available loading dock when they arrived randomly at the site (Line 35 of Figure 3-7). In effect, this highly subjective (but realistic) constraint determined the maximum truck arrival rate that the facility could effectively service given a fixed loading dock configuration and unloading time (e.g. number of available docks, average unloading time, etc).

The number of available loading docks (number of servers, μ) for the queuing analysis was determined using two potential facility configuration scenarios:

- Current Scenario: Use existing loading dock and material handling space configuration.
- Facility Upgrade Scenario: Modify adjacent building to increase the number of useable loading docks and material handling space.

Using the queuing theory calculator, the maximum traffic handling capacity of each configuration scenario was determined. These results were superimposed along with an estimate of the number of JIT deliveries required per PC35 fuel cell (Figure 3-8).

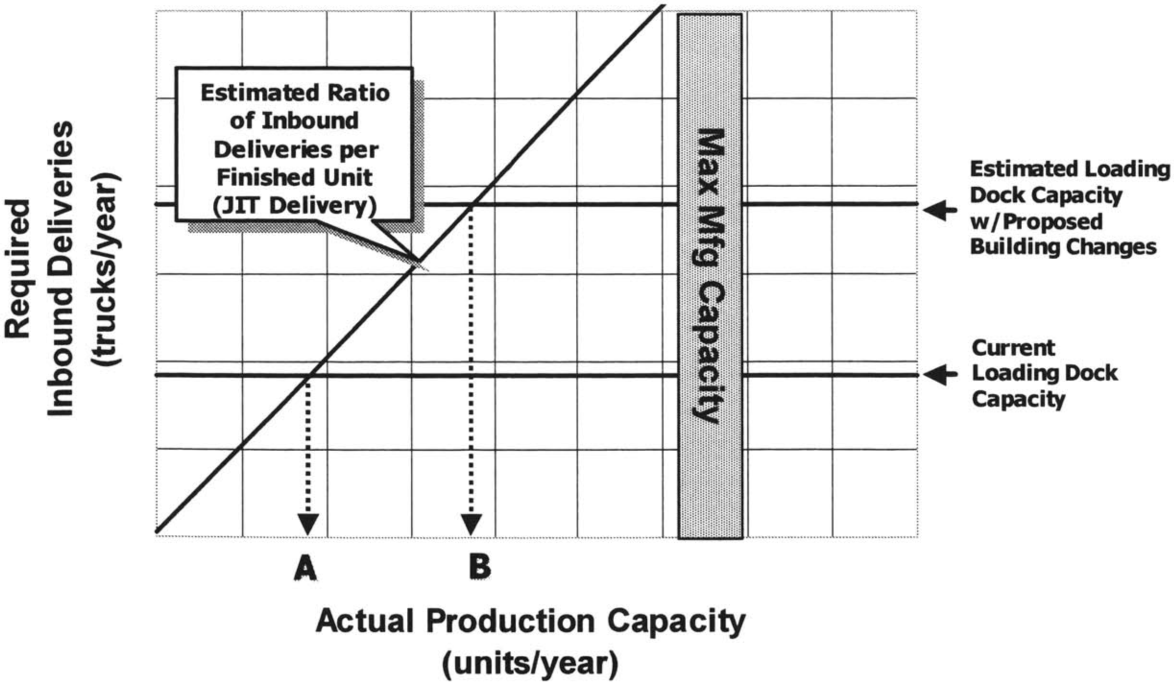


Figure 3-8: Site is Traffic Constrained for JIT Deliveries

Figure 3-8 reveals that a bottleneck will exist at the site's truck loading docks (for either facility layout scenario) that will limit the production facility's maximum annual throughput (based on available space). The solid black diagonal line represents an estimate of the number of JIT deliveries required from the current supplier network to manufacture a given number of PC35 commercial fuel cells. Point A delineates the estimated annual production capacity of the site if the current building configuration (existing loading docks) is used in conjunction with the planned JIT delivery scheme. Since the number of inbound deliveries the site can accommodate is limited, the production line would be "starved" for raw materials (subassemblies). In a similar manner, Point B is the estimated maximum annual capacity of the site if the existing facility is modified to increase the number of useable loading docks and material handling space.

3.3.3 Strategic Implications

To address the inbound traffic constraint problem outlined above, the following major recommendations were made to UTCFC's senior management to shift the site's throughput bottleneck to its theoretical maximum production capacity:

- Utilize and upgrade an adjacent facility to provide higher traffic throughput
    - Increases the number of loading docks available for offloading all truck sizes (increases number of servers, μ)
    - Provides additional subassembly storage (laydown) areas
    - Provides smooth, clockwise material flow throughout the manufacturing facility
- Acquire a local supply logistics center (SLC)
    - Reduces the number of trucks arriving at the facility by using consolidated deliveries (reduces arrival rate, λ)
    - Enables coordination of on-site deliveries (eliminates Poisson arrival process assumption)
    - Supplies additional space to kit and maintain inventory buffers

The recommendations outlined above provide a simple, cost-effective solution for extending the useful life of the existing facility before UTCFC would be forced to acquire additional manufacturing capacity. Figure 3-9 illustrates how a local supply logistics center (SLC) can effectively shift the bottleneck from inbound trucking traffic constraints to the facility's maximum manufacturing capacity. This cost-effective solution extends the useful life of the facility (the current loading dock configuration can easily handle consolidated deliveries for entire range of possible factory throughput), allowing UTCFC to mitigate its risk exposure to the uncertain fuel cell market demand while simultaneously minimizing the risk of production capacity overcapitalization.

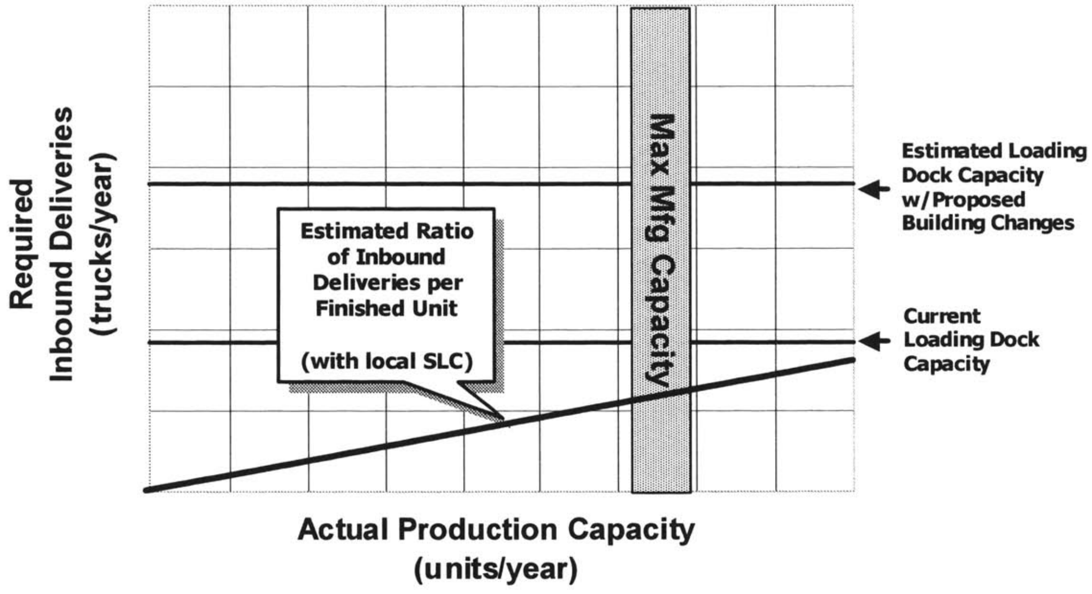


Figure 3-9: SLC Extends the Useful Life of the Existing Facility

3.4 New Facility Siting Methodology

A major finding from the current facility capacity study was that UTCFC must acquire a new manufacturing facility in a relatively short period of time if customer demand for the PC35 even moderately meets forecasted values. Two key questions that inevitably flow from this realization are:

- **When** should the new facility siting process begin?

- **Where** should the new facility be located (sited)?

3.4.1 Determining Facility Siting Lead Time

Knowing when to start the new facility siting process is highly variable between enterprises since every company has varying needs and resources. In the case of large corporations such as UTC, ample resources are available at the corporate level to assist the individual divisions in their site selection process. Leveraging these resources, UTCFC can significantly cut the lead time required to site and acquire a new manufacturing facility.

To generally determine the lead time required to complete the new facility siting process, a benchmarking study was conducted of a recent manufacturing facility relocation project at UTC's Carrier division. Carrier was selected as a good benchmarking source for the following reasons:

- All UTC divisions had similar access to corporate-wide site selection resources
- The recent relocation project was believed to adequately represent a realistic timeline for UTCFC's new facility siting process
- Lessons learned from the move could be integrated into UTCFC's strategic plan

Based on the results of the benchmarking study, a realistic lead time "window of opportunity" was developed. This lead time "window" was superimposed on UTCFC's forecasted demand curve along with the expected maximum facility capacity to yield a planning start date as depicted in Figure 3-10. (Note: Point A delineates the expected time (quarter and year) when UTCFC can expect to reach maximum capacity at its current facility assuming a local SLC is used to consolidate inbound deliveries). The results of this study revealed that the site selection process would need to begin much sooner than previously expected.

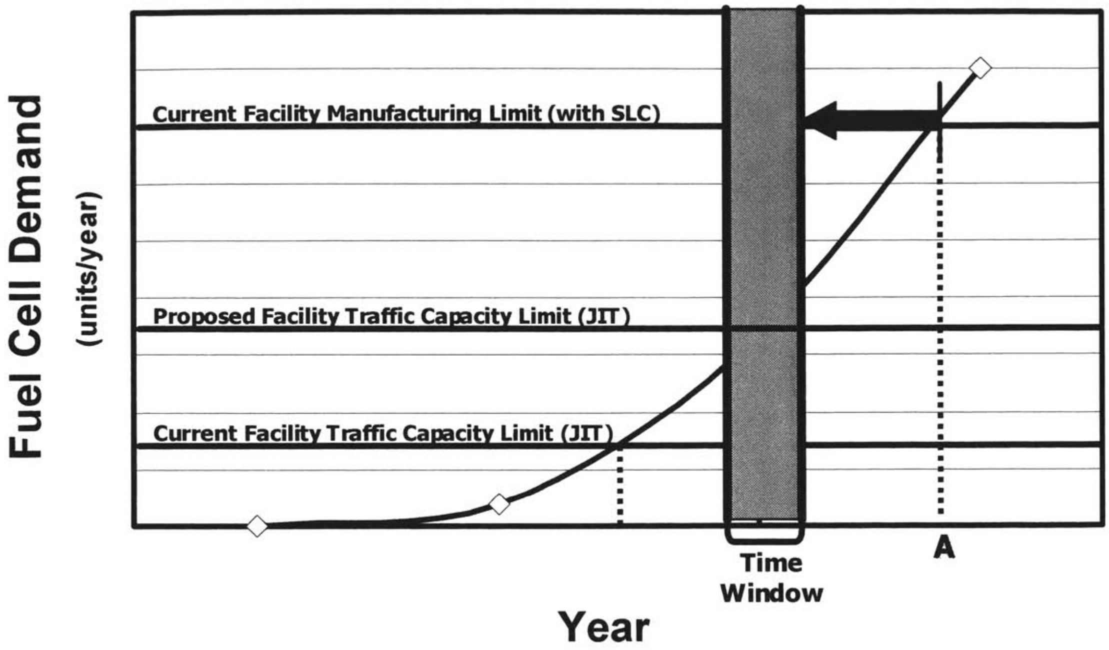


Figure 3-10: Using Benchmark Data to Determine Lead Time

3.4.2 Dynamic Strategic Planning (DSP)

The key component of the new facility siting process is the dynamic strategic planning (DSP) methodology. As previously described in Chapter 2, DSP provides a rigorous, risk-adjusted framework for making difficult facility siting decisions in the face of highly uncertain product demand. Combining elements of cost modeling, decision analysis, and probabilistic market demand, DSP empowers managers with a flexible plan that can be synthesized with qualitative factors to make the best possible decision for the organization given the quality of information at hand.

This section will explore the DSP model specifically developed for UTCFC. Although this model is highly modified to meet the needs of one company, many of the methodologies and processes discussed in the section can be used in numerous other contexts.

3.4.2.1 Elements of DSP

DSP consists of six fundamental principles, three concerning the nature of decision-making while the remainder stipulate how the plan evolves over time. These principles as defined by de Neufville[25] are summarized below:

- The plan should be technically proficient such that the analysis identifies frontiers to the problem. This process usually involves modeling techniques such as optimization or simulation.
- There is no single "correct" strategic plan since the stakeholders naturally project their preferences and prejudices on the plan.
- All involved stakeholders must agree to the plan's objective.
- All forecasts are wrong. DSP attempts to quantify the discrepancies and account for them in the plan.
- The plan should be flexible enough to change according to future events that *may* occur.
- Desired methods of adding flexibility are best identified using principles from financial real option theory.

The DSP methodology enables the combination of the six fundamental principles by utilizing traditional decision analysis and cost modeling techniques. These methodologies can be broken down into four distinct categories:

- Modeling & Optimization: The models define production functions that represent the possible solutions to the problem. These functions can later be manipulated using traditional system optimization tools such as linear programming to achieve a technically sound solution. Simulation tools such as Monte Carlo analyses are often useful since the function or process may be too vague to effectively model using static, deterministic values.

- Probabilistic Forecasting: Forecasting is always inaccurate. However, detailed studies on the issue in question or the pooling of knowledgeable individuals can usually determine the degree of inaccuracy. Historical trends in combination with regression analysis tools can also be used to at least assign approximate probabilities to the likelihood of specific events taking place.

- Decision & Sensitivity Analyses: Decision trees are often utilized to combine the results of the modeling exercise and probabilistic forecasts into a cohesive strategic plan. By combining the possible solutions outlined in the modeling process with the chances of each scenario occurring, a "best" solution can be determined given the quality of data on hand. A sensitivity analysis should immediately follow this exercise to determine the range over which the "best solution" holds. Highly sensitive solutions suggest further refinement may be required.

- Real Options Analysis: Adding flexibility to any strategic plan is nearly always useful; however, it also adds costs. Real option theory can be used to place a value on the cost of adding flexibility to the plan and investigating which options provide the most value (flexibility) for the least cost.

3.4.2.2 Structure of the DSP Model

As shown in Figure 3-11, Phase II of the strategic roadmap illustrates the key inputs and final outputs of the DSP tool when it is applied in a new manufacturing facility siting process. The input values from Phase I of the facility siting process are a "short list" of potential new sites that were deemed worthy of further analysis by the company's senior management team (Milestone 1). Each of these "short list" sites were screened during Phase I to ensure they adequately met key **qualitative** criteria prior to entering the next screening phase. A thorough **quantitative** analysis of each "short list" site is then conducted in Phase II in preparation for analysis by the DSP tool.

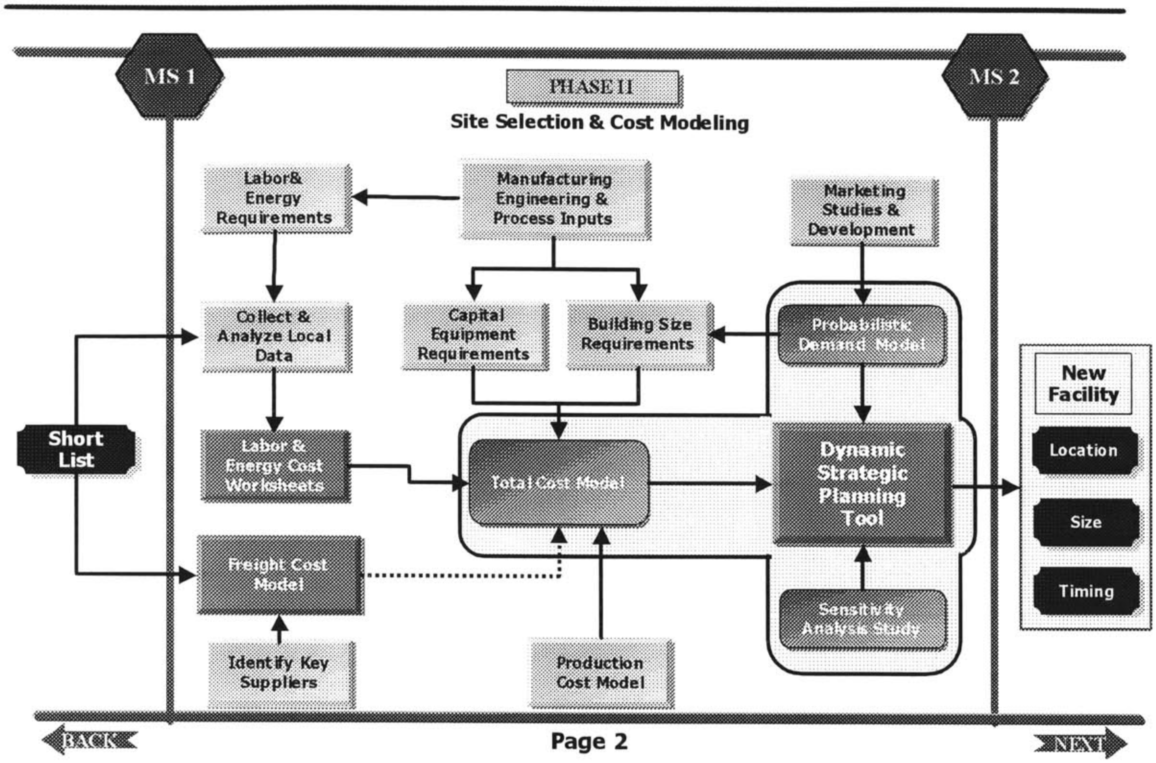


Figure 3-11: DSP Model Inputs and Outputs

3.4.2.3 Scope of DSP Tool

Although DSP tools normally require cost modeling of the entire enterprise, the site-specific cost model developed for UTCFC was optimized to emphasize only *operational costs*. These costs are usually defined as variable costs that are utilized to make or transport the product (labor, energy, freight, etc) but are not actually part of the finished product (raw material/subassembly costs). Operational costs were used for the following reasons:

- The (variable) cost of subassemblies and other raw materials were largely fixed by contractual arrangements with key strategic suppliers and would not vary significantly from site to site.
- New facility layouts and capital equipment costs were assumed to be identical from site to site.

- Operational costs were the only major variables that were site dependent. Examples include:
  - Local labor rates (management and hourly)
  - Local energy costs and availability
  - Local real estate and construction costs (per square foot)
  - Local tax rates and business incentives
  - Inbound freight costs from known key suppliers
  - Outbound freight costs to major customer epicenters
- Operational costs were the only costs that could be readily manipulated by UTCFC (many other costs were inelastic or volume specific).

The Total Cost Model developed for UTCFC was purposefully designed to calculate the *total cost* of producing the PC35 fuel cell for any given volume and facility location. By designing the cost model in this manner, the model could be utilized for cost studies other than the site selection process. However, many sections of the cost model that were assumed to be independent of facility location (such as subassembly/raw material cost), were "zeroed" to limit the scope of the cost model and provide ease of use. Figure 3-12 shows the major operational cost drivers incorporated into the cost model.

Figure 3-12: Operational Cost Drivers

3.4.2.4 Cost Modeling

This section will discuss each of the key operational cost drivers in detail. Although much of the discussion will be specific to the needs of UTCFC, the main purpose of the discussion is to allow the reader to understand the source of the cost data and how it was derived.

3.4.2.4.1 Freight Cost Model

Once the cost modeling project was underway, it became readily apparent that the cost of inbound and outbound freight would be **the major cost driver** in the total operational cost for manufacturing the PC35. Some of the key factors driving this issue included:

- UTCFC had already established fixed long-term contracts with a network of key subassembly suppliers. Consequently, their subassembly manufacturing plant locations effectively determined the traveling distance for inbound freight shipments.
- The large physical size and weight of the finished subassemblies severely limited the amount of truckload consolidation that could be accomplished for inbound shipments.
- The finished PC35 unit required one outbound (flatbed) truck per unit.
- The current metal frame manufacturer contract required the frame to arrive fully assembled at the UTCFC site. Consequently, inbound frame shipments required one flatbed truck per frame.

The high cost of freight relative to other operational costs significantly affected the DSP process since siting the new facility closer to supplier and/or customer epicenters would provide significant freight cost savings over the life to the facility. Although the location of these epicenters was likely to change over time, the long-term nature of the supplier relationships as well as the expected customer location concentrations were deemed to be fairly stable over the next five to ten years. A robust freight cost model could empirically determine if inbound or outbound freight was the major freight cost driver, allowing UTCFC to strategically locate its new facility.

Since it was given that the freight cost model would only have to perform an optimization for a single facility location, an enumeration method was utilized to determine the total inbound and outbound freight cost for a given annual production volume. Major elements of the model are discussed below:

UTCFC Facility Locations

The Scenario Generator section of the freight cost model allowed the user to input up to five locations that were being considered as potential UTCFC manufacturing sites. This "short list" of sites was normally generated during Phase I of the strategic planning process (see Figure 3-4). Once the city, state, and zip code of each site was entered, the model would automatically perform a lookup function using the zip code to determine the geographic latitude and longitude of each potential site.

Inbound & Outbound Shipping Distances

The freight cost model was designed so that the user would simply input the city, state, and zip code of any component supplier making inbound shipments to the proposed UTCFC manufacturing site. The model would automatically perform a lookup function similar to the one described above to determine the latitude and longitude of the supplier's facility. Additional data was required to determine the number of shipments that were required from the supplier on an annual basis to manufacture a given number of fuel cells.

Input from UTCFC's marketing efforts was used to determine the expected market demand (as a percentage of total sales) from each of the nine domestic marketing regions as well as international sales to Europe and the Far East. A representative city was chosen from each region to act as the geographic centroid for all outbound product shipments to that particular region. Zip codes from these representative cities were automatically converted into latitude and longitudes while international shipping costs were handled manually using quoted rates from global shipping companies.

To calculate the distance between each potential UTCFC manufacturing site and its suppliers/customers, the great circle distance was calculated using the following formula:[26]

$$\boxed{D = 60 * \arccos[\sin(Lat1)*\sin(Lat2) + \cos(Lat1)*\cos(Lat2)*\cos(abs(Long1-Long2))]}$$

Where: D = great circle distance in nautical miles
Lat1/Long1 are coordinates of origination site (radians)
Lat2/Long2 are coordinates of destination site (radians)

A circuity factor of 1.22 was used to convert the great circle distance to actual miles traveled for a typical domestic roadway system.[27]

Cost per Mile Determination

Due to its large size and widespread operations, UTC has pre-negotiated freight rates for nearly every point-to-point trucking route in the continental United States. Additionally, many of these trucking lanes have multiple vendor bids, allowing individual UTC divisions to choose their preferred carrier based on past relationships, price, or availability.

The freight cost model leverages this freight rate information by automatically data mining the Microsoft Access database (that contains the data) for all point-to-point freight rates. This is accomplished by using zip codes to lookup standardized *origin codes* for each location. The origin codes are then used in conjunction with Microsoft Query to extract pertinent data from the freight rate database. The data is then averaged and automatically placed in the appropriate spreadsheet to yield an **average cost per mile** for shipping.

Final Freight Cost Determination

Visual Basic for Applications (VBA) code was written to automate the entire process once input data was entered into the model. The annual freight cost for a given site was determined using the following general formulation:

For All Potential UTCFC Sites:

Inbound

For Each Supplier:

Number of Inbound Shipments Required to Produce Given Demand x **Average Cost Per Mile from Supplier to UTCFC (mined from database)** x **Estimated Mileage from Supplier (Great Circle distance)** = **Annual Inbound Cost**

Outbound

+

For Each Customer Locus:

Number of Outbound Shipments to Each Customer Epicenter (based on demand forecasts) x **Average Cost Per Mile from UTCFC to Customer (mined from database)** x **Estimated Mileage to Customer Epicenter (Great Circle distance)** = **Annual Outbound Cost**

Annual Freight Cost

Once the calculations were completed, the freight cost model displayed total inbound and outbound freight costs on an annual basis for any given demand volume. This process was then automatically repeated for all five potential UTCFC manufacturing sites. Figure 3-13 depicts a representative output graph from the freight cost model.

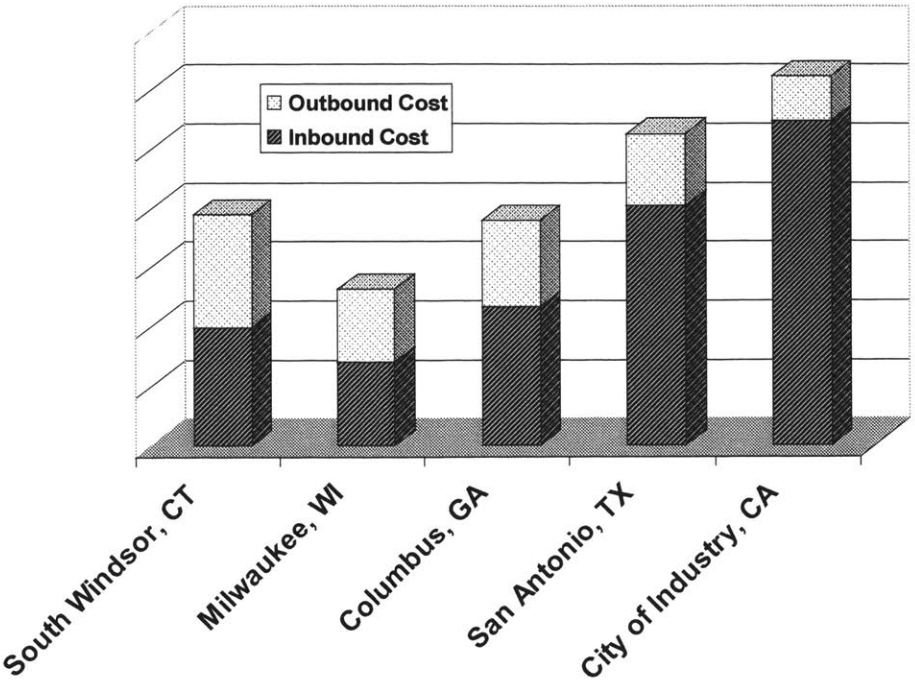


Figure 3-13: Sample Output from Freight Cost Model

3.4.2.4.2 Labor Cost

Labor costs were estimated for each potential UTCFC site by using a standardized labor force that was derived from UTCFC's recently completed preliminary production plan. Each potential facility was assumed to be manned by a set number of hourly workers comprised of predetermined skill sets and wage levels. The factory was also manned with a small number of salaried workers comprised of plant management, manufacturing engineers, and shop floor supervisors.

The local labor rates for each potential facility site were determined using U.S. Bureau of Labor Statistic's National Compensation Survey.[28] Using this comprehensive source of data, UTCFC's job descriptions were cross-referenced to standardized job classifications to obtain the appropriate local labor rates. Finally, expected total labor hours were used to obtain a comparable annual labor cost estimate for each potential site.

3.4.2.4.3 Energy Cost

Energy costs proved the most difficult variable to estimate, driven primarily by the different heating and cooling needs of the various regions. Additionally, UTCFC did not have an accurate estimate of the energy required to manufacture the PC35 fuel cell since actual production had not yet started.

To overcome these obstacles, the cost model assumed the new facilities' energy needs would closely resemble the "light manufacturing" profile published in U.S. Department of Energy statistics[29]. Although this assumption was only a rough approximation of UTCFC's future energy needs, it provided a common reference point for comparing annual energy usage and cost between competing facility sites.

3.4.2.4.4 Building Cost

The DSP tool assumes three possible scenarios for future building capacity: High Capacity, Medium Capacity, and Low Capacity. Since the model does not explicitly assign size (ft^2) values to these scenarios, it is up the strategic planner to determine the appropriate size of the building to meet these criteria. Obviously, the size a High Capacity building for fuel cell manufacturing would be enormously different than a building designated for automobile manufacturing. Although many factors are used to determine the appropriate building size for each scenario, some of the key factors include:

- Production line size
- Physical product size
- Expected life of the building
- Required space for non-manufacturing activities (admin, shipping, etc)
- Forecasted product demand (growth)

The DSP tool requires the user to carefully consider the future needs of the company when deciding building sizes since a "lost sales" penalty is incurred if the building's estimated production capacity cannot meet forecasted product demand.

The cost of leasing or buying an existing "light manufacturing/warehouse" type of facility is relatively easy to determine for each potential facility site. Recent data is readily available on many commercial real estate websites while more detailed data can be obtained by contacting these firms directly. Once the cost per square foot is determined for each potential site, the cost of buying or leasing a building can be easily determined for each building size scenario.

3.4.2.4.5 Total Operational Cost

Once all of the cost data is gathered using the Microsoft Excel-based tools and models imbedded into the strategic roadmap, the information is entered into the DSP tool's cost spreadsheet. The purpose of the spreadsheet is to consolidate all of the estimated operational costs for manufacturing a given number of fuel cells at a single potential site, with all costs calculated on an annual basis. In theory, this cost estimate should accurately represent the major costs incurred by the company for manufacturing fuel cells at a given site less the cost of purchasing raw materials and semi-finished subassembly units.

Depreciating assets such as buildings and capital equipment are amortized over the organization's standard depreciation period(s) using the straight-line method and an appropriate opportunity cost of capital.

3.4.2.5 Probabilistic Market Demand

A major input into the DSP modeling process for new facility siting is a probabilistically-based demand forecast. Although beyond the scope of this project, many sources exist for generating this type of marketing data, including:

- Marketing surveys
- Historical data analysis (regression analyses and similar methods)
- Test marketing
- Future trend studies

- Consumer demand modeling

The probabilities assigned to demand forecasts can either be fairly involved using probability density functions (e.g. normal) or simple, discrete values. As is true with any modeling process, the quality of the data inputted in the model directly impacts the integrity of the model's results. The demand data and associated probabilities are later incorporated directly into a decision tree software application.

In the case of UTCFC, relatively little historical data exists for the fuel cell market since only one fuel cell model has been commercially available to date. Additionally, the current high cost of producing fuel cells has highly skewed this demand data to R&D and governmental uses, providing non-representative data for forecasting future fuel cell demand. Complicating the matter, the PC35 fuel cell has not finished the final design stages, making final product cost and subsequent market demand difficult to estimate.

In response to this uncertain market, UTCFC's DSP tool currently models product demand in a highly simplistic manner (high, medium, and low) using discrete probabilities for each demand scenario. To numerically determine UTCFC's annual production rate, the size of the overall fuel cell market is estimated for a six-year period, with a UTCFC-assigned market share percentage for each demand scenario. The reader should note that as better market demand information becomes available, the model could easily be modified to utilize a more-precise probabilistic density function.

3.4.2.6 DSP Mechanics

Using Visual Basic for Applications (VBA) programming, the DSP tool has a user-friendly interface where all input data is entered into the model. The General Data Input page is used solely for entering generic data on items that do not change significantly over time such as the company's opportunity cost of capital (hurdle rate) and standard depreciation periods for buildings and equipment. The Scenario Generator page provides the user with an intuitive interface for entering demand forecasting data and proposed facility sizes that can easily be modified to iteratively run the model using different planning scenarios. The Cost Model page provides a heavily annotated spreadsheet for entering the gathered cost data and freight cost model results.

Using a VBA-based programming macro, the DSP tool calculates for each year the net present value (NPV) for each demand scenario and facility size, imposing a "lost sales" penalty if facility capacity cannot adequately meet demand. These NPV values are then added up over the model's six-year time horizon to generate a matrix that displays the results of all possible scenarios. The tool can also be modified to calculate present values (PVs) instead of NPVs by simply using $0 as the product's price. In this case, the decision tree software package will need to be informed to recommend the "least cost" option. Figure 3-14 delineates the DSP tool's framework. Figure 3-15 depicts a sample DSP model present value (least cost) matrix for one site.

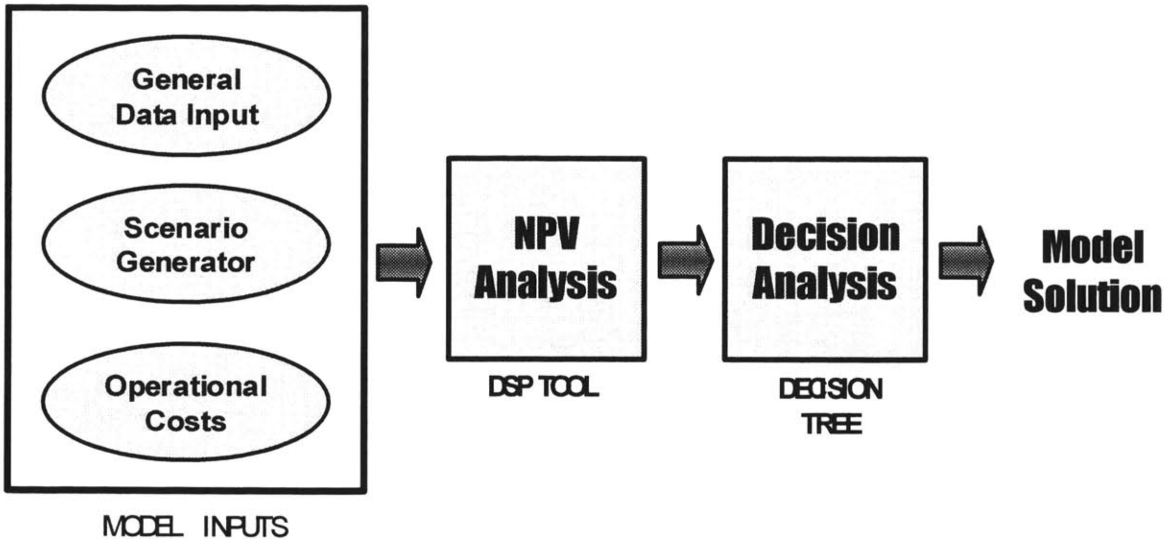


Figure 3-14: DSP Model Framework

Plant Size (sq ft)	Present Value	Demand Scenario
50,000	($20,205,938)	LOW
75,000	($20,027,975)	
120,000	($20,445,501)	
50,000	($30,955,954)	MEDIUM
75,000	($28,754,433)	
120,000	($25,918,634)	
50,000	($44,305,390)	HIGH
75,000	($42,103,869)	
120,000	($38,141,131)	

Figure 3-15: DSP Model Sample Present Value Matrix

Once the DSP model formulates the PV (or NPV) matrix, these values are entered into a decision tree software program along with associated probabilities based on the product demand forecast. For this particular project, TreeAge Software Inc.'s Data™ software package was utilized to generate recommended solutions. This robust decision tree software package was chosen since it could be setup to automatically import PV values directly from the Excel workbook and easily handled probability density functions for the market demand data. Although the current DSP tool did not make full use of the product's functionality, future versions of the DSP tool could easily be expanded without creating the need to shift to a more robust decision tree software package.

Once the PV and probability values (or PDFs) are entered into the decision tree program for all of the facility sites being considered, the program automatically calculates the "best solution" based on the provided information. Specifically, the decision tree recommends which option (e.g. build a high capacity facility at Site D) produces the lowest cost (or highest net present value) given the probabilistic demand data that was inputted into the model. A generic sample portion of the decision tree setup for analyzing a single site (Site D) is depicted in Figure 3-16.

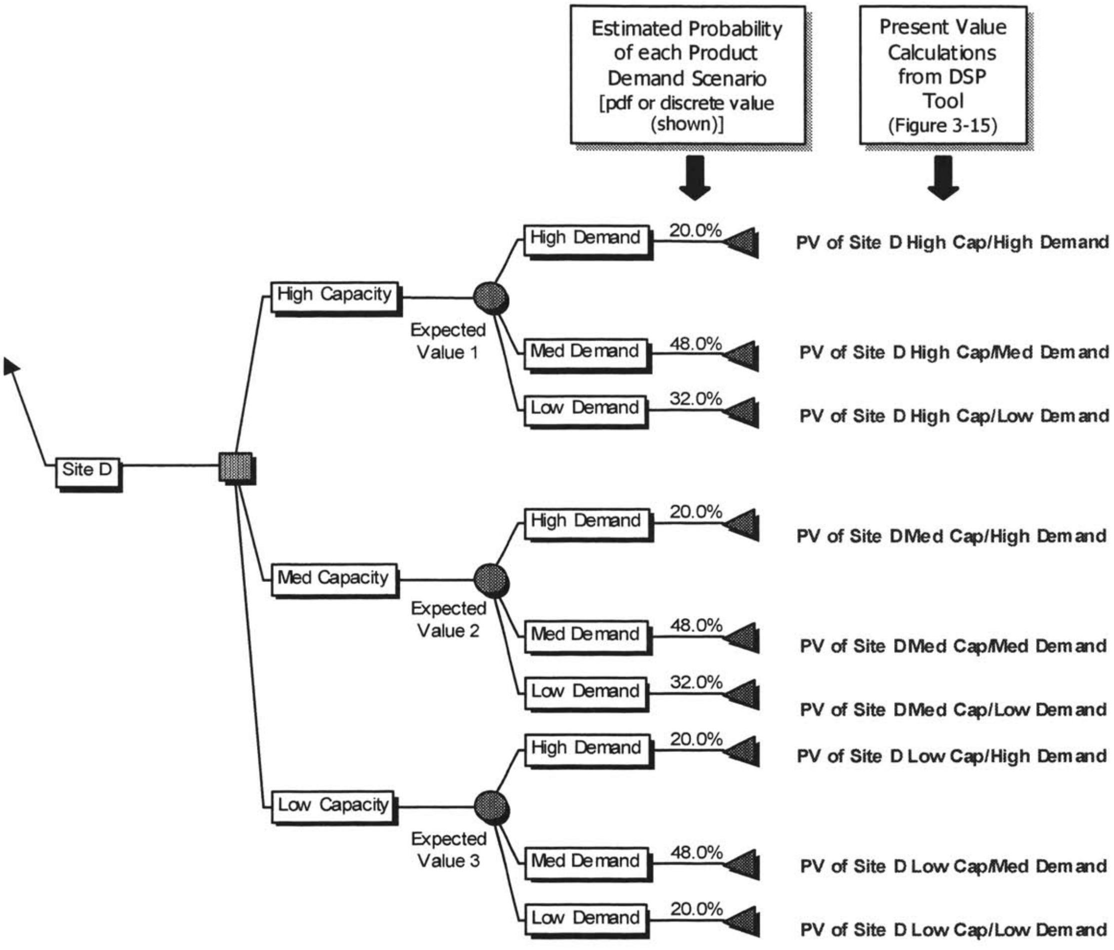


Figure 3-16: Single-Stage Decision Tree Sample (partial)

To setup the decision tree for each potential site, the DSP model is run using the site's specific operational cost data, generating the PV matrix (see Figure 3-15). The present values are then entered into the terminal node of the decision tree that corresponds to the node's decision flowpath (e.g. Site D-Low Capacity Facility-Medium Demand Scenario). Finally, product demand probabilities (discrete or PDFs) are entered into the decision tree based on market demand forecasts. This process is repeated for each potential site being analyzed (for illustrative purposes, a simple demand probability scenario is depicted in Figure 3-16 using a High/Medium/Low demand breakdown with associated discrete probabilities). Once all the data is entered, the decision tree software package will calculate the expected value of each branch of the tree and then compare each of these values to yield the best (least cost) scenario for a given site. This process is then repeated for each potential site with the final recommendation being determined by comparing the "best scenarios" generated for each site (e.g. build a high capacity plant at Site A).

Although beyond the scope of this project, the DSP model can be implemented using a multiple-stage (time phased) approach. The use of multi-stage decision trees allows major facility capacity decisions to be made in a stepped fashion with later capacity decisions hinging upon the results of near-term capacity decisions. For example, once a new site and facility size are determined using the methodology outlined above (Stage 1), then another capacity expansion decision (Stage 2) can be made several years later based upon the initial facility capacity (size) and long-term future product demand forecasts. This is accomplished by adding an entire new layer of decision branches that stem from the current terminal nodes of the single-stage decision tree. Expected values are then calculated starting from the terminal nodes of the future branches and expending all the way to the present day decision node. The end result of this analysis would result in a "best" (least cost) solution that recommends a two-staged capacity decision (e.g. build a medium capacity facility at Site A next year and then another high capacity facility at Site E in five years). The reader should note that although the multi-stage approach may lead to more cost effective solutions, the lack of availability of long-term product demand forecasts and cost structures may make this method very difficult to implement.

3.2.4.7 Sensitivity Analysis

Theoretically, the solution recommended by the decision tree program would be "the correct answer" only if product demand and costs were precisely known. In reality, the probabilities used for demand forecasting fall on a continuum between "highly uncertain" and "virtually known," with each case being highly situational. In the same light, values derived during the cost modeling process are also prone to uncertainty.

To determine the overall robustness of the DSP model's solution, a series of one-way sensitivity analyses should be conducted to determine which inputs create the largest change in the model's output. This process, which is similar to shadow pricing in linear programming optimizations, allows the strategic planner to determine not only the sensitivity of the final solution to various model inputs but also the input range over which the model solution remains stable.

Most advanced decision tree software programs have sensitivity analysis tools built into the decision framework, precluding the user from spending enormous amounts of time iteratively running many simulations with varied inputs. Once the sensitivity analysis is performed on each input variable, tornado charts can be generated to visually depict which input created the largest change in the recommended solution. With the sensitivity analysis in hand, the strategic planner can then allocate additional resources in proportion to the effect the input variable had on the final solution. Additional resources may be directed towards gaining a more thorough understanding of market demand or incorporating a better cost model.

4. IMPLEMENTATION

At the time of the internship project, the PC35 commercial fuel cell was entering the final stages of the design process. Consequently, many key variables regarding the fuel cell manufacturing process remained unanswered due to the highly dependent nature of these variables on the final details of the fuel cell's design.

However, UTCFC's early decision to outsource much of the actual subassembly manufacturing to strategic suppliers enabled the concurrent completion of a preliminary manufacturing facility design that performed the final assembly and testing processes. Since much of this work had been completed by the end of the internship period, the preliminary plan provided sufficient detail to permit at least an initial analysis of the key cost drivers in the total operational cost model. Additionally, the preliminary assembly line design and material flow considerations dictated the type of facility that UTCFC would likely require in the future as it expanded its production capacity.

4.1 Operational Cost Driver Study

Using the information available at the time of the internship, a preliminary operational cost driver study was completed using the tools outlined in Chapter 3. The purpose of the study was threefold:

1. Identify potential future sites for UTCFC manufacturing operations once production capacity was exceeded at the current manufacturing facility.
    - Goal: Identify suitable UTC-owned or leased manufacturing facilities in each region of the country that would act as a representative sample of the expected labor, energy, and freight costs for the given region. Vacant UTC-owned facilities were used in this study to leverage UTC's existing assets; thereby minimizing facility acquisition costs.

2. Determine the relative size and ranking of the key operational cost drivers.

- Goal: By finding the relative size of each remaining operational cost (labor, energy, and freight) for all regions examined, the total cost model would reveal which costs were the key leverage points in siting a new manufacturing facility. By focusing on these leverage points, senior management could effectively determine the best location for the new facility by basing its decision on minimizing the cost driver with the highest marginal return.

3. Determine the estimated inbound and outbound freight costs for each potential future location.
    - Goal: Freight costs were determined to be the main operational cost driver over the life of the manufacturing facility. The freight cost model was used to accurately estimate the annual inbound and outbound freight costs for each potential site assuming UTCFC's current strategic supplier base.

4.1.1 Potential Future Site Selection

Five potential sites were chosen to provide a representative "sample" of the regional costs that UTCFC would likely encounter if it chose to locate its future manufacturing operations in that region. Each site was selected from a UTC-maintained database that listed vacant facilities already owned or leased by UTC. The facilities were further screened to ensure they generally met the estimated building type and space needs of a future UTCFC manufacturing facility. The representative sites selected for the study are outlined in Table 4-1.

Facility Location	Region	Criteria
South Windsor, CT	**Northeast**	▪ Current (default) location of UTCFC manufacturing and operations ▪ Access to engineering & design personnel ▪ Co-located with some subassembly
Milwaukee, WI	**Midwest**	▪ Located near many strategic suppliers (lower inbound freight costs) ▪ Centralized location for outbound shipping to both coasts
Columbus, GA	**Southeast**	▪ Low cost labor ▪ Lower energy costs ▪ Convenient access to major seaports
San Antonio, TX	**Southwest**	▪ Low cost labor ▪ Lower energy costs ▪ Synergy with other local UTC operations
City of Industry, CA	**California**	▪ Co-located with major customer base (minimize outbound freight cost) ▪ Co-located with other UTC operations ▪ Convenient access to major seaports

Table 4-1: Site Selection Criteria for Cost Driver Study

4.1.2 Cost Driver Study Findings

The results obtained from the operational cost driver study are detailed in this section. For illustrative purposes, the relative costs for each cost driver are shown using a graphical format for each representative site. The reader should note that the actual cost values have been removed and/or disguised to protect intellectual property.

4.1.2.1 Energy Cost Results

Annualized electricity and natural gas usage estimates were made for the future PC35 assembly line using current PC25 production facility and DOE-defined "light manufacturing facility" statistics. Although this technique provided only a rough estimate of the expected energy usage for the future manufacturing operations, the energy consumption data provided a common basis to evaluate each potential site. In addition to the expected energy requirements for actual production, each site's energy consumption was adjusted using DOE statistics for the expected heating and cooling loads in each region for a 100,000ft^2 facility. Using regionally-adjusted energy cost data, Figure 4-1 illustrates the estimated relative energy costs for operating identical facilities at each proposed location.

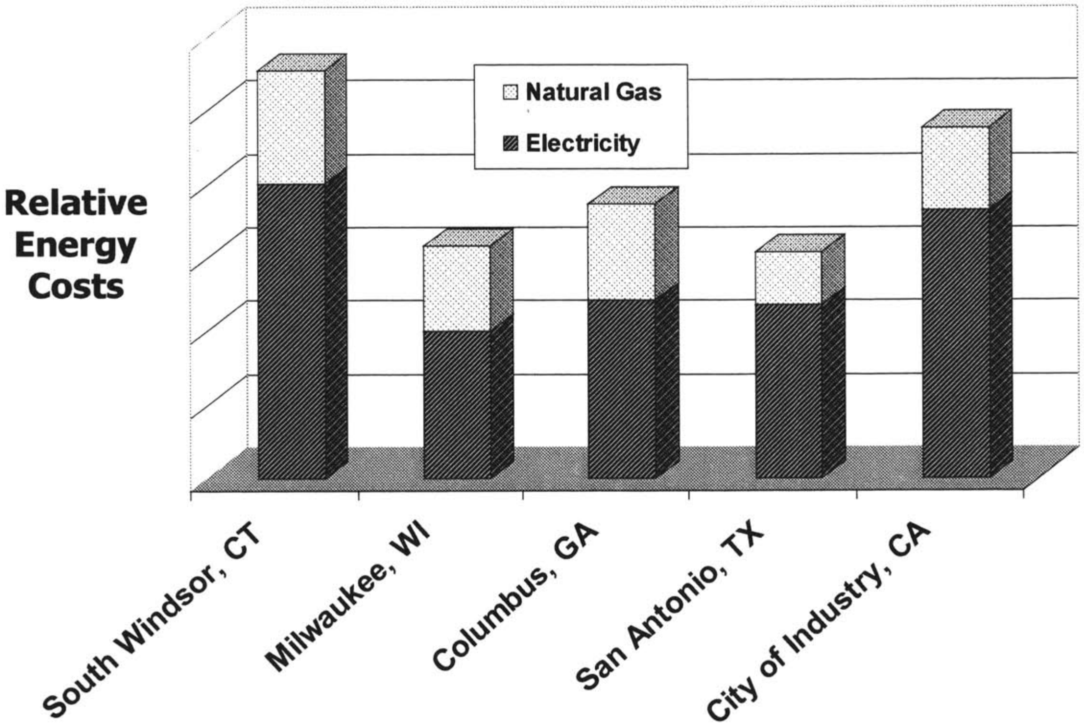


Figure 4-1: Relative Annual Energy Costs

Figure 4-1 reveals annual estimated energy costs vary significantly between the proposed sites. A closer examination of the underlying data reveals that almost all of the cost differences are directly attributable to regional energy price differences with only minor additions due to regional heating and/or cooling needs.

4.1.2.2 Labor Cost Results

Utilizing the preliminary production plan for the PC35 fuel cell, a two-shift workforce structure with appropriate pay grade breakdowns was constructed to estimate the facility's annual labor costs. Assuming two 7-hour shifts working 240 days per year, labor rates were determined using regionalized U.S. Bureau of Labor statistics as detailed in Section 3.4.2.4.2. Figure 4-2 shows the relative annualized labor costs for each potential location:

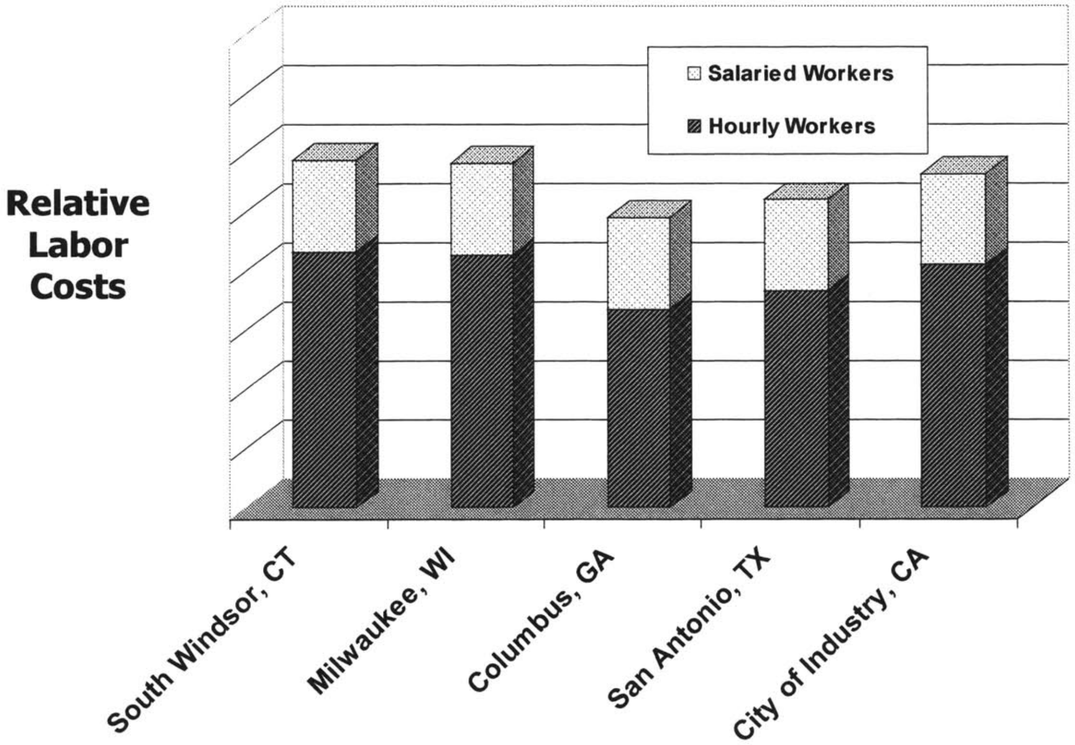


Figure 4-2: Relative Annualized Labor Costs

Figure 4-2 illustrates that relative total labor costs do **not** vary significantly across the geographic regions. However, labor costs comprise a significant portion of the total operational costs for the facility on an absolute basis and highlight the necessity of using design for manufacturability (DFM) concepts so that assembly-related labor hours are minimized.

4.1.2.3 Building Cost Results

Although the actual sites for the cost driver study were selected based on the availability of UTC-owned facilities as outlined in Section 4.1.1, building acquisition costs were estimated for leasing a 100,000ft^2 "light manufacturing" facility in the given location. These costs were estimated to highlight the relative cost of commercial real estate in each region as well as to include all operational costs in the study. As previously noted, UTCFC may be able to leverage UTC's existing fixed asset base to acquire a new manufacturing facility at a significant cost savings. Figure 4-3 shows the relative lease rates for acquiring a manufacturing facility in each region:

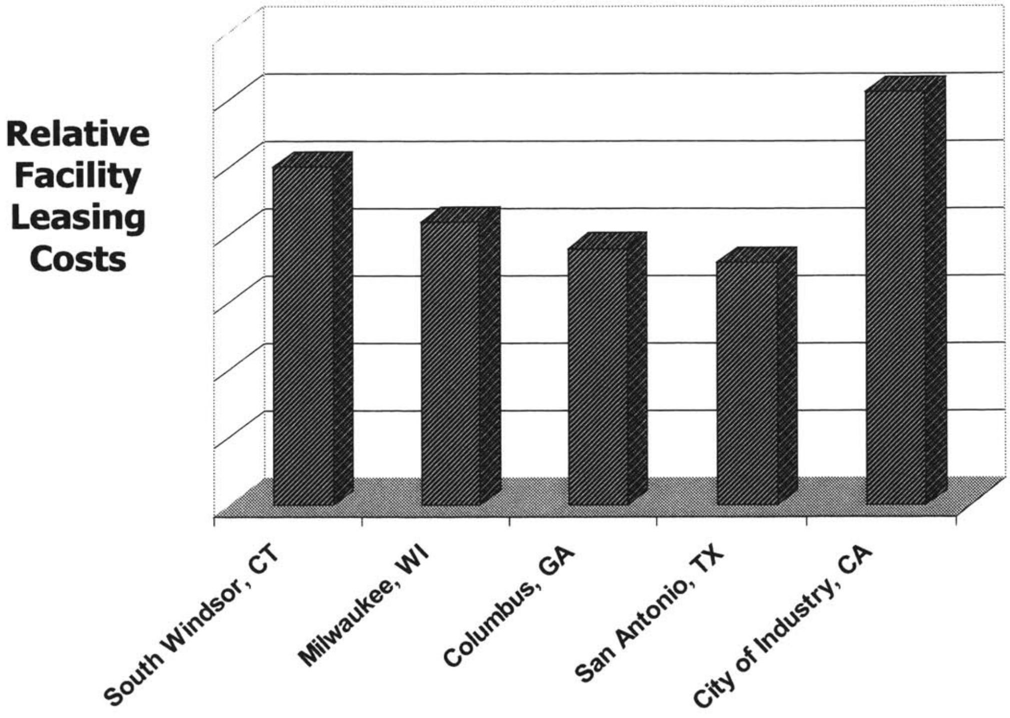


Figure 4-3: Relative Building Lease Rates for 100,000ft^2 Facility

4.1.2.4 Freight Cost Results

The freight cost model was utilized to estimate the annualized inbound and outbound freight costs for each potential facility location. When calculating the inbound freight cost, the current manufacturing facility locations of UTCFC's strategic supplier network were used to determine the shipping distance from the key subassembly suppliers to each potential UTCFC site. Outbound freight costs assumed a 1000 unit/year production rate and customer locations based on current market demand forecasts. Figures 4-4 illustrates the freight cost model's output if a daily delivery scheme was used to supply the manufacturing facility.

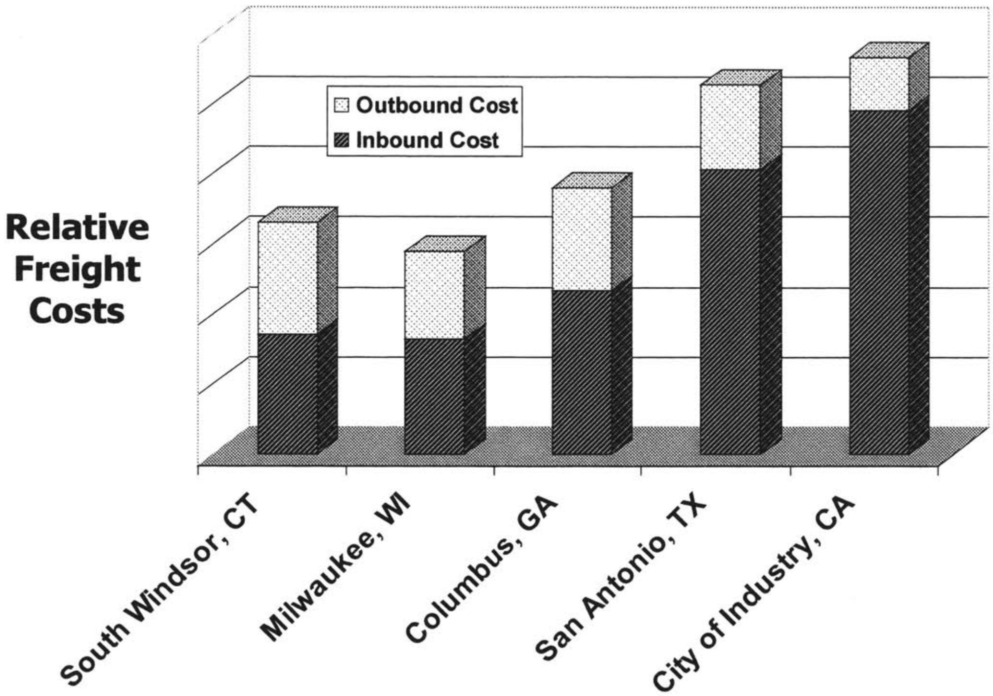


Figure 4-4: Relative Annualized Freight Cost (Daily Deliveries)

An analysis of the freight cost model's output reveals the following cost driver issues:

- In general, inbound freight is the major driver of total freight cost. This is largely due to the large number of inbound shipments required from key suppliers to assemble a single PC35 fuel cell. Additionally, the physical size and configuration of most subassemblies creates only limited opportunities for inbound trucking consolidation.

- UTCFC's current South Windsor facility has (surprisingly) low overall freight costs due to the on-site manufacturing of the large fuel cell stack assembly as well as being co-located with the fuel processing system vendor. By locally sourcing these major components, significant savings are realized in inbound shipping.
- Although siting a plant in California near the center of the largest domestic customer base significantly reduces outbound shipping costs, the comparatively large number of inbound shipments required from a distant, fixed supplier base negates outbound freight savings, making it the highest freight cost location. A similar logic held for the San Antonio, TX and Columbus, GA locations. This finding was counterintuitive to senior management's previous belief that being closer to the largest concentration of customers would be the best alternative.
- Inbound freight costs could be significantly reduced by leasing a nearby supply logistics center (SLC) to minimize the number of inbound deliveries. Although some subassemblies still required JIT deliveries due to their large physical size, many of the other subassemblies could be delivered on a weekly basis, further reducing the number of inbound trucks.
- The fixed locations of the current strategic supplier network proved to be the controlling factor in the freight cost model.

4.1.2.5 Cost Driver Study Composite Results

Figure 4-5 is a composite view showing the relative contribution of each cost driver to the total operational cost for each facility site. An examination of the composite graph reveals the following findings:

- Inbound and outbound freight costs are the main drivers of operational costs and should be a primary consideration when siting a new manufacturing facility.
- Labor costs are the second biggest cost driver and should be reduced as much as possible by DFM and other techniques.
- Although energy costs vary significantly from region to region, they are not a significant factor in an absolute sense in the total operational cost.
- Building costs are not a significant factor in the total operational cost.

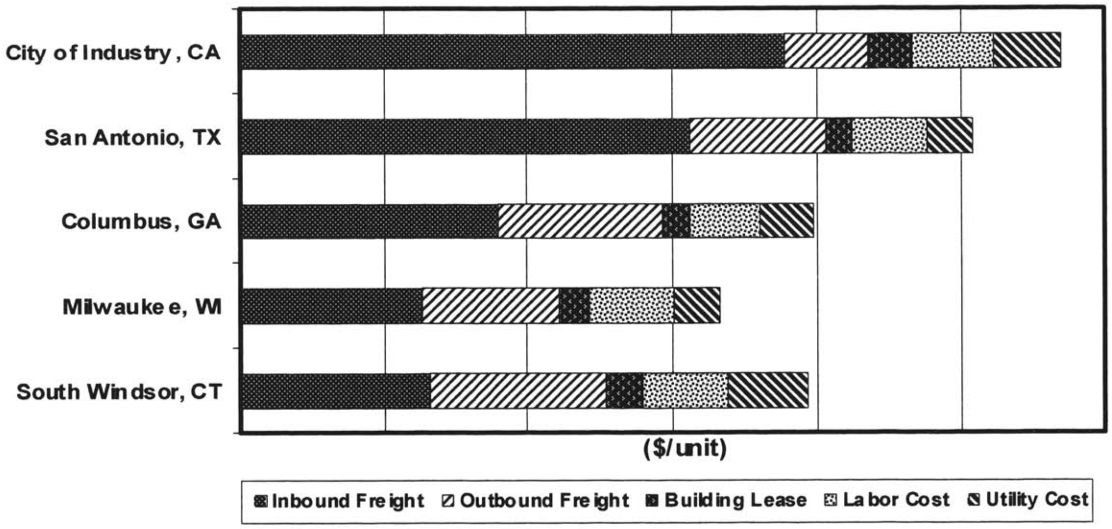


Figure 4-5: Composite View of Relative Operational Costs

As previously mentioned, several of the findings from the operational cost driver study proved contrary to senior management's previous paradigms concerning the siting of a future fuel cell manufacturing facility. Several of these initial paradigms included:

- Labor costs were assumed to be the major cost driver (outside of material costs) for fuel cell manufacturing. Consequently, UTCFC would be forced to manufacture fuel cells in low labor cost regions such as the southern United States or Mexico.

- Supplier facility locations were not a key criterion during the supply chain design process since inbound freight costs were not considered a major cost driver.
- California (or a similar western state) was assumed to be an ideal facility location due to demand forecasts that expect over 30% of sales to occur in that state.

4.1.3 Recommendations

Based upon the findings of the operational cost driver study and other strategic considerations, the following recommendations would allow UTCFC to produce PC35 fuel cells in the lowest cost manner:

- Once the PC35 production process is stabilized in the South Windsor facility, UTCFC should re-perform a thorough operational cost analysis to determine if other sites would provide a lower cost structure. Based on current data, South Windsor remains a relatively low cost site for future capacity expansion while also providing qualitative aspects such as on-site engineering support.
- A thorough analysis of inbound freight costs reveals that several subassemblies (e.g. the metal frame) that cannot be easily consolidated for shipping are the major cost drivers in this vital segment. Consequently, UTCFC should consider shipping these parts in an unassembled manner and completing the final assembly process at the UTCFC site. Although the extra production steps will increase the final assembly cost, these incurred costs are negligible compared to the annual savings realized from reducing the frequency of inbound shipments.
- If delivery of partially assembled subassemblies is not possible, UTCFC should consider sourcing these large components at the local level to minimize inbound freight costs. This is especially true for non-critical components (e.g. the frame) that can easily be manufactured by local companies.

- If the current supplier network remains fixed for the foreseeable future, UTCFC should immediately consider leasing a local SLC to decrease inbound freight costs as volume production begins to ramp-up.
- UTCFC should periodically revisit its strategic supplier network to determine if local sourcing of key components is possible. For vital suppliers with proprietary technology, UTCFC should actively investigate the possibility of co-locating at a common site if future fuel cell demand warrants increased expansion of the capacity base.

The recommendations outlined above should be taken into account with other cost saving measures such as improved DFM and lean production processes to ensure the PC35 fuel cell is cost competitive with other forms of assured power.

5. CONCLUSION

The content of this thesis is based upon a project that is only in the early stages of development. However, the methodologies described in this thesis can be effectively utilized in many other organizations to provide a rigorous framework for making capital expenditure decisions in an uncertain demand environment. Since almost every manufacturing enterprise faces these type of decisions during some point in its existence, the contents of this thesis should provide valuable tools for the decision-making process.

Although sufficient data such as market demand information was not yet available during the course of the internship, the strategic roadmap and decision-making tools provided to UTCFC should allow the organization to quickly site a new manufacturing facility if fuel cell market demand exhibits similar characteristics to the PC market of the late 1980s. With the addition of several key pieces of information that are expected to become available in the near future, UTCFC should be able to effectively utilize the DSP tool to make risk-adjusted siting decisions to meet future market demand.

Utilizing the information that was available during the internship period, the operational cost driver study provided several counterintuitive insights that provided clear guidance to UTCFC's senior management as they streamline the supply chain design process and begin to look ahead to the facility siting process. By demanding rigor in the decision-making process, the meticulous process leads to:

- High quality information that allows senior managers to identify the key leverage points in the system (which lever to push)
- Findings that are occasionally counterintuitive to the enterprises' normal assumptions (which direction to pull the lever)
- Logical conclusions concerning why the key leverage points should be manipulated.

5.1 Key Insights

This thesis reveals several key insights into the facility siting process, especially in the face of a highly uncertain demand environment. Several of these insights were gleaned from the occasionally messy process of developing a generic framework for facility siting while other insights transpired while attempting to put the framework and its associated tools into action. These major insights are delineated below:

- Most companies do not use a rigorous framework for making many of their crucial decisions. Consequently, many of these decisions are sub-optimal, creating additional costs and a sustained loss of competitive advantage.
- Many senior managers do not properly understand the role of risk in their work environment, choosing either to ignore it or simplify it into a rigid, discrete value.
- Tools and methodologies are available to help management properly deal with risk and mitigate its effect on the organization.

5.2 Strengths and Weaknesses of Approach

This thesis often noted the key assumptions that were made throughout the process when constructing the strategic roadmap and its associated risk-mitigating tools. However, many of the strengths and weaknesses of the approach were often not apparent until the tools were actually used near the conclusion of the internship. From this experience, a list of the major strengths and weakness of this approach was quickly determined. A short description of these lessons learned is outlined in Table 5-1.

Strengths	Weaknesses
▪ Provides rigorous framework for decision-making ▪ Identifies key leverage points ▪ Provides clear direction to future managers using roadmap metaphor ▪ Methodology adaptable to almost any business scenario ▪ Tools are Excel-based to provide users with familiar interface	▪ Cost modeling difficult to accomplish, especially without current production processes in place ▪ Difficult and/or costly to gather probabilistic market demand data, especially in new market segments ▪ Model may be too difficult to explain to managers with little technical background

Table 5-1: Strengths and Weaknesses

5.3 Areas for Further Analysis

As UTCFC moves forward into the initial production runs of the PC35 commercial fuel cell, many of the uncertainties currently facing the company will become more concrete as data becomes available. This data can then be used to make informed, risk-adjusted decisions concerning its present and future production capacity needs. Several of the areas that have been identified for further analysis include:

- Accurate market demand forecasts to determine UTCFC's present and future production capacity needs. These forecasts will also supply the ***timing*** for beginning the site selection process (see Figure 3-10).
- Cost/Benefit analysis for leasing a local supply logistics center to minimize inbound freight costs. This study should compare the cost of leasing and operating a nearby warehouse with the volume and cost of the inbound freight shipments.
- Determination of actual energy needs for the production of the PC35 fuel cell. This value should become apparent during the first full year of production.

5.4 Summary

Although the methodologies outlined in this thesis are certainly not the only means of dealing with uncertain market demand for products that currently are not in production, they do provide a rigorous framework for making risk-mitigated decisions. The DSP tool has been used successfully in the past for decision-making in large capital-intensive projects, especially in the energy and transportation arenas. However, I believe the simplified methodology distilled in this project will effectively achieve the desirable result of producing risk-mitigated decisions without employing all of the methods available under the larger DSP framework.

As UTCFC moves forward during the next several years with its commercial fuel cell production, it will be interesting to observe how DSP and the other tools developed during the project help UTCFC to make better production capacity decisions as more accurate information becomes available.

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6. Endnotes

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