Development of a Global Facility Location Analysis Tool

By

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Bachelor of Science in Mechanical Engineering (1998)

Submitted to the MIT Sloan School of Management and the Engineering Systems Division in Partial Fulfillment of the Requirements for the Degrees of

Master of Business Administration
AND
Master of Science in Engineering Systems Division

In conjunction with the Leaders for Manufacturing Program at the

Massachusetts Institute of Technology
June 2008

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ABSTRACT

With an economy and customer base that is global, companies are increasingly expanding outside their home country's borders. Many times this is done to take advantage of lower labor or material rates, to increase proximity to the customer, to decrease logistics and transportation costs, to avoid tariffs and other taxes as well as many other factors. How does a company take advantage of the benefits of global operations while still taking into account the corporate strategy and risks associated with a location? By looking beyond standard matrix analysis tools that provide a one number comparison of potential locations, this thesis will expand the existing tools to incorporate the views of Enterprise Architecting to provide a more complete picture of how the decision to expand to one location versus another supports the desired architecture of the firm. This thesis combines analytical hierarchy process with a two level decision matrix to quantify the score of each location. A risk profile was developed to quantify the risk associated with specific locations and criteria in order to provide a more complete picture of the potential costs and benefits of building a facility in a certain location. This more complete view of location analysis will provide a tool that is both repeatable and reliable in its results and allows for an objective decision to be made on location in terms of the critical factors.

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Acknowledgments

I would like to thank all of my friends and family back home in Washington but most of all my Mother for all of her love and support throughout school and in particular during the internship when I would call her at all hours of the day and night from exotic locales. Thanks to my classmates and friends for their tireless support and friendship throughout the past two years. Thank you to all of the people at Schlumberger who allowed me access to their sites and their countries of operations. I appreciate the efforts of Jon and JR who helped me to learn more about the locations I was visiting. To Michelle Bernson, whose persistent encouragement resulted in my attending LFM, must go a special thank you. Finally thank you to The Boeing Company for their generous sponsorship and support that enabled me to attend the LFM program.

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Biographical Note

Briana Johnson was born and raised in the Puget Sound region of Western Washington. She attended the University of Washington, graduating in 1998 with a Bachelor of Science in Mechanical Engineering. Joining The Boeing Company in 1998 she spent over 6 years as a Liaison Engineer on the 747 program. Much of her time working with the 747 program involved the application of lean principles and practices to the engineering office and production support functions. Immediately before joining the LFM program, as a student sponsored by The Boeing Company, she spent a year working for the 787 program on process development. She is currently planning to return to work for The Boeing Company in the Puget Sound area.

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1. Introduction

Several topics will be covered as this thesis progresses. Chapter 1 provides an overview of the problem statement, company background, including discussions on the process previously used to determine locations for expansion, and the scope of the tool proposed within this thesis. Chapter 2 reviews the current literature covering the problems and methodologies used within this thesis. Chapter 3 discusses the methodology used to develop a tool that satisfactorily solves the problem. Subsections of Chapter 3 are each devoted to the location decision matrix that results from the research conducted in support of this thesis: the incorporation and use of analytical hierarchy process as a decision tool; the development of a risk profile to attempt to quantify some risk associated with making location decisions; and how the enterprise architecture frameworks are supported by this model. The results from data gathered during a proof of concept analysis of four representative countries are reviewed in Chapter 4. Chapter 5 discusses the results, including major patterns observed and an interpretation of the results. Finally, Chapter 6 reviews the recommendations for further work on this topic.

1.1. Problem Statement

There are expansion decisions that affect the ultimate success or failure of companies as they grow. These decisions can be a determining factor between a venture that is merely successful and one that is highly profitable. They can also provide a competitive advantage in both a strategic and an operational perspective. When making the decision to expand operations, a company is building a piece of the future architecture of its enterprise. As a result, the choices can have a large impact on the seven views represented in an enterprise architecture framework[1]: strategy, policy and external factors, products and services, information technology, processes, organization, and knowledge. Expanding without taking into consideration the effect potential locations will have on the future desired architecture can limit future maneuverability of the enterprise. When making decisions about facility expansion not only does the architecture of the enterprise need consideration but also the process and methodology used in making location

[1] Nightingale, D. & Rhodes, D. (2007). *Enterprise Architecting.* Massachusetts Institute of Technology.

decisions. The decisions need to be objective, allow for multiple stakeholder perspectives and enable decision makers to see an accurate portrayal of the risk associated with a particular location. How to integrate these multiple goals into a tool that provides accurate decision information within a process that is repeatable and reliable is the intent of this thesis. It is possible to consider the architecture of the entire enterprise when making specific and possibly isolated facility location decisions using a methodology that gives objective results, targets multiple stakeholders and allows for future improvement.

1.2. Company Background

Schlumberger Limited is one of the world's leading oilfield services companies, founded in 1926. Schlumberger employs 80,000 employees, representing 140 nationalities in approximately 80 countries around the world. Their focus is on supplying technology, information solutions and integrated project management with the goal of optimizing well performance for their customers in the oil and gas industry with 2007 revenue in excess of $23 billion. With principle offices located in Houston, Paris and The Hague and a market capitalization of $102 billion[2], the company comprises two major business segments. The principle activities of the oilfield services segment are products and services that support the entire life cycle of core industry, operational processes including formation evaluation through directional drilling, well cementing and stimulation, well completions and productivity to consulting, software, information management and information technology infrastructure services. The other major segment is WesternGeco, the world's largest seismic company, which supplies advanced acquisition and data processing services.[3]

Schlumberger offers an unrivaled technology portfolio, global expertise and exceptional service quality to their customers, ensuring that their customers are able to maximize productivity

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[2] *Google Finance*. Schlumberger Limited (ADR) Retrieved March 7, 2008, from http://finance.google.com/finance?q=slb&hl=en

[3] *Schlumberger Company Website*. Backgrounder, Schlumberger. Retrieved March 7, 2008, from http://www.slb.com/content/about/backgrounder.asp?

throughout the life of the reservoir. The differentiating technologies that Schlumberger offers focus on four key activities: 1. finding the reservoir through industry-leading seismic technology, 2. reaching the reservoir more efficiently through the use of technology to enable optimal well placement and maximum recovery, 3. connecting the reservoir by designing and manufacturing customized solutions that can be modified throughout the life of the field to ensure longer and more efficient production, and 4. producing the reservoir using digitally enabled technologies to ensure critical data is captured and acted upon in order to allow improved production performance.

1.2.1. Needs for Global Expansion

Schlumberger is experiencing growth in several areas of their products and services. The increase in demand for their products and services, especially in manufacturing intensive areas such as completions, has required an increase in the manufacturing capacity for these products. The competitive advantage that Schlumberger offers its clients are: [4]

- Deep domain knowledge of exploration and production operations
- The service industry's longest commitment to technology and innovation through their network of 23 research, development and technology centers
- Strong local experience in addition to a large global reach into more than 80 countries and the diversity in thought, background and knowledge that their global nationalities bring
- A commitment to excellence in service delivery anytime, anywhere

This increased growth, the company's stated commitment to its clients, and potential for low cost advantages encourage Schlumberger to look globally for additional manufacturing capacity. While the internship and resulting location analysis tool were conceived for analyzing locations for potential manufacturing facilities it is applicable to any facility to be located globally.

[4] *Schlumberger Company Website.* Backgrounder, Schlumberger. Retrieved March 7, 2008, from http://www.slb.com/content/about/backgrounder.asp?

1.3. Previous Location Decision Processes within the Company

Schlumberger identified the need for a quick, accurate, objective location analysis tool to satisfy its expansion needs. Previously, decisions were under less time pressure and more cumbersome methods could be used. For instance, a complete cost analysis could be done on several locations allowing for a much more detailed, albeit longer, process of analysis to occur. In this event, the results of the analysis are easily imported into instruments and documents required for justifying capital asset requests. However, this still did not ensure that the process was conducted in the same manner from project to project, since the process appeared to involve different individuals who were not always able to share best practices or insights with colleagues who later performed similar analyses. This encourages a duplication of effort that is not desirable from the company's standpoint. The new tool will allow the company to turn the ability to make these decisions quickly into a strategic advantage, allowing them to possibly create first mover advantages or to reap the benefits of a location more quickly.

Anecdotal evidence also suggests that decisions could be made with undue emotional investment on the part of individuals with a bias for a specific location or strategic direction. It is natural human behavior to have difficulty in looking at one's home location in an objective manner, not to say that it is unachievable, but over the course of many decisions the probability that bias does not play a role in decision-making certainly cannot be ruled out. Including multiple opinions can help to alleviate this problematic situation, but that also creates additional problems of reaching a consensus. With no stable process and criteria to use, the ability of people to agree on the analysis of a location is further hampered by this potential for increasing disagreement on the criteria used to conduct the analysis.

1.4. Scope of Location Analysis Tool

Main objectives of the location analysis tool to be created were specific to the company's situation. First, the company wanted a methodology created that would allow them to transfer knowledge of the tool and the process by which the tool is intended to be used throughout the individual segments and across the different segments of the company. This tool and its associated standard work instructions needed to allow for repeatable and reliable execution. The tool should not be designed to require the author or initial company experts' presence in order to allow for successful execution. By having a standard methodology, tool and work instruction results from many projects can be compared to one another. In this way a feedback mechanism is built into the use of the tool that encourages those who use the tool to modify not only the tool but also the standard work instructions as different users on projects of different magnitude and scope identify improvements.

Another equally important area that required addressing was the objectivity of the methodology and tools used. In the past when tools have been used within the company, they were created ad hoc for each individual situation. Through interviews and anecdotal stories there also appeared to have been instances where no tool was used but instead there was a move toward a certain location because of a large perceived advantage to that location or a strongly held opinion by influential individuals. For example, low wages, special economic zones, tax incentives, etc. have played a role in the selection of past sites. While these are valid reasons to consider a particular site they often do not paint a clear picture of the entire business environment in which business will be conducted. The resulting tool will need to have mechanisms in place to increase the objectivity of the analysis and results. Input will be required from multiple levels of the organization in order to accurately portray the strategies and objectives of those different levels. The tool will also need to be able to separate those levels from each other so as not to bias one level of decision making from another.

Being able to adjust the parameters on which locations are scored is an important feature for the tool. In order to facilitate discussion, mediate disagreements, and explore alternatives, the parameters and their effect on the resulting output of the tool should be easily adjusted. This will allow users and those who will be making decisions based on the output to explore "what if" scenarios, to explore how deferring to another's opinion affects the results of the analysis.

Including a way for the tool to quantify risk is one of the most critical improvements over analysis methods used in the past. The goal is for risk to be included to show the range of potential outcomes for a location in lieu of a one number answer corresponding to "the score" of a particular location. As this is a new application of incorporating risk into an existing tool the exact determination of "how" to calculate the amount of risk associated with certain criteria will invariably need to be adjustable in order to accommodate increased learning about the affect of applying multiple risk effects on the analysis of locations.

1.4.1. What is included, what is not included and why

Because the focus of the company's goals for the project were more centered on developing a robust methodology that could be used as a platform on which to improve and also incorporate functionality and analysis capabilities, the focus shifted away from researching and developing the most comprehensive list of criteria available. Certainly alternate lists of criteria exist in the literature, but incorporating new criteria into the tool developed as part of this thesis should be relatively easy and straightforward as new criteria are discovered to be pertinent to the location decisions Schlumberger is making. Included in this thesis is a defined methodology, suggestions for improving the tool and areas for further research and development.

Because criteria development was not the main focus, developing a way to incorporate risk into the analysis was the first goal included in the tool. Effort was made to determine a way that risk can be calculated and not treated as another independent variable that is chosen by the person conducting the analysis. Also, developing a risk profile that was reasonably representative of the actual experiences based on previous decisions and their actual outcomes, proved to be a design feature that required detailed consideration. To enhance the lack of objectivity in the current tools, the ability to have multiple viewpoints independently used in the analysis, is included as a design feature.

Creating a tool that has the ability to adjust the different parameters and see the effect on the analysis that was included, allows the tool to be used as a starting point for discussion among the stakeholders. Including this feature enables project stakeholders to change one, or many parameters and see if the recommendation for location selection change based on the new analysis. Since previous tools did not provide this ability, there was a sense by those seeing the results that they may not accurately represent the situation from their viewpoint. Unfortunately what is not included with the tool is quantitative data to use in rating locations with respect to the criteria. The author found independent information for the variety of locations under consideration difficult to obtain. Specifically finding generally accepted data to define what represents subjective ideas like "good", "excellent", or "poor" for the wide variety of economic, human resource, logistical and capital criteria available for use in future decisions was not obtainable. Due to the time constraints of the internship upon which this thesis is based, an actual test case and associated results are not included as part of the thesis. Instead a potential manufacturing facility to produce a representative sample of Schlumberger Completions products in four potential locations was used as a proof of concept for the tool. The recommendations and results from this proof of concept case were reviewed with management to ensure that the proof of concept results met the goals of the project.

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2. Literature Review

As companies become increasingly global enterprises with more complex organizational, product and process, supply chain and customer issues, there is a need to define new concepts for how to manage these extended enterprises. With the concept of a system of systems[5] we see the increasing organic nature of terms used to define enterprises.[6] The concept of enterprise architecting is now a well-established field of academic study. Much of the current work involves defining the aspects of art and science in the definition of these complex systems.[7] In looking at how the location decision affects the enterprise, we are essentially looking at ways to transform the enterprise.[8] The tool developed within this thesis is one tool that can be applied to the specific problem of locating a facility, which in turn is a piece in the transformation of the enterprise.

Analytical Hierarchy Process (AHP) is an established method with many applications that allows for the consideration of qualitative and quantitative aspects of a decision. For example, AHP has been used as a method to benchmark the performance of facility management[9]; as a tool to assess different strategies for an organization based on environmental factors and their probability of occurrence[10]; for evaluating supply chain management[11]; and managing the risks within the

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[5] Maier, M. W. Architecting Principles for Systems-of-Systems Chantilly, VA: John Wiley & Sons, Inc., 1999. 267-284.

[6] Piepenbrock, T. F., Fine, C. H. & Nightingale, D. J. Toward a Theory of Evolution of Business Ecosystems: Enterprise Architectures, Competitive Dynamics, Firm Performance and Industrial Co-Evolution. March 2008. 22 p.

[7] Nightingale, D. J. & Rhodes, D. H. (2004, Mar.). *Enterprise Systems Architecting: Emerging Art and Science within Engineering Systems*. MIT Engineering Systems Symposium. Massachusetts Institute of Technology.

[8] Rouse, W. B. (2005). Enterprises as Systems: Essential Challenges and Approaches to Transformation. *Systems Engineering*, *8*(2), 138-150.

[9] Gilleard, J. D. & Yat-lung, P. (2004). Benchmarking Facility Management: Applying Analytical Hierarchy Process. *Facilities*, *22*(1/2), 19-25.

[10] Tavana, M. & Banerjee, S. (1995). Strategic Assessment Model (SAM): A Multiple Criteria Decision Support System for Evaluation of Strategic Alternatives. *Decision Sciences*, *26*(1), 119-143.

[11] Sharma, M. & Bhagwat, R. (2007). An Integrated BSC-AHP Approach for Supply Chain Management Evaluation. *Measuring Business Excellence*, *11*(3), 57-68.

supply chain[12]. In the context of this project and thesis, AHP is used as a tool for determining the strategic objectives of the organization as it relates to location expansion.

The facility location decision has used many tools and techniques. The main themes recently seen are the globalization of facilities. This can be attributed in part to the lowering of trade barriers and the emergence of just in time delivery from suppliers and to customers. Location decisions have been made to minimize transportation costs, gain access to markets and satisfy content requirements. This thesis combines previous efforts into a comprehensive enterprise architecture tool. AHP has been used to compare locations based on many of the factors that are also included in the tool developed in this thesis.[13] AHP represents one level of analysis conducted in conjunction with this thesis. It was not used as the only analysis method because it becomes time consuming as the number of criteria becomes large. Also having multiple levels of analysis allows for multiple stakeholder inputs while partitioning each stakeholder into a particular segment.

The research on determining risk presented several options. The AHP method was found to have great potential in quantifying the risk seen in processes in order to determine on which factors you should focus mitigation plans.[14] Other methods that have been researched are compliance to a measurement variable such as lead-time. If a certain process or product is not meeting targets, it is labeled as a risk item. However, these methods require an additional determination to be made on the part of the data collector, making them an independent variable. This means that additional criteria are needed to define the appropriate levels and subjective assessments to be made.

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[12] Gaudenzi, B. & Borghesi, A. (2006). Managing Risks in Supply Chain Using the AHP Method. *The International Journal of Logistics Management, 17*(1), 114-136.

[13] Jiaqin, Y. & Lee, H. (1997). An AHP Decision Model for Facility Location Selection. *Facilities, 15*(9/10), 241.

[14] Gaudenzi, Barbara and Antonio Borghesi (2006). Managing risks in the supply chain using the AHP method, *The International Journal of Logistics Management,* Vol. 17, No. 114-136

3. Methodology

3.1. *Approach to Solving the Problem*

3.1.1. Understanding Previous Location Decision Tools and Methods

Upon arrival at the company site in Texas and understanding the broad project scope, the author spent time with a group of people who had recently completed a manufacturing facility location analysis using the existing tools and techniques within Schlumberger. Through a meeting with these individuals, the author was exposed to the pace of expansion that would be required to meet projected demand. We also spent considerable time working through the matrix that they used to evaluate the potential sites. They used a list of criteria which they had individually weighted on a scale of 0 to 1 and then evaluated each location by assigning a 1 to 5 score corresponding to how well the location satisfied the criteria. This matrix produced a single number representing the aggregate score for each location. We discussed several critical criteria categories, although no formal categories existed within the matrix used, including the importance of utility availability and quality, real estate option and costs, taxes, and human resources. The location recommended from this matrix was then used to develop a detailed Capital Asset Request. The specific financial information for the location was used in conjunction with projected demand for a representative sample of parts that would be built in the new facility to create a profit and loss projection for the next 10 years. As part of this model, assumptions were made as to the rate of production ramp up, the desired steady state mix of production outsourcing, the development of the supplier base, and the development of the human capital.[15]

3.1.2. The Schlumberger Completion Products Manufacturing Value Chain

In order to gain an understanding of the products encompassed by the completions manufacturing group, the author spent approximately two months in two globally diverse

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[15] Howard, Danny; Milner, Steve; Pickering, Patricio O. Personal interview. 27 June 2007

manufacturing facilities. Both facilities manufactured the same category of products from the completions and artificial lift product lines and had come under the control of Schlumberger as a result of their acquisition of Camco International, Inc. The first location was a Texas manufacturing facility where the focus of several weeks there would be an understanding of the operations from customer service and order entry through the manufacturing and support operations to the warehouse where the final products are shipped to the customers.

Customer service was the first stop on the exposure agenda. The catalogue that the Schlumberger field organizations see is comprised of the standard configuration items that can be ordered for a set price. However, if the configuration desired is not represented or is slightly different, then the request is reviewed and a quote is presented showing the final cost of the item. The customer service organization also acts as the bridge between the field organizations and the factory. Changes in status, expedited requests, coordination with production planners and delivery date updates are all communicated through this channel.

Once an order is finalized and sent to the facility, the order entry and review process starts the process of releasing work to the manufacturing facility. Orders are released after all required engineering design changes have been completed. Once orders are released the customer service representative is responsible for keeping track of the status of that order for the field organization. They are encouraged to go directly to the manufacturing engineers to obtain accurate up-to-date information on the status of the order. Once the order is complete the customer service representative also manages the shipping process in the sense that they ensure that all appropriate bills of lading and invoices are complete before releasing the order to be shipped. The process of order quoting encompasses the activities of obtaining the accurate price and delivery dates for orders that are not part of the standard catalogue. Most of the modifications requested are in the form of "same as this part except…" so it is the quoting department's responsibility to classify and determine the cost and lead-time for these changes.

Changes are classified into four numbered buckets where the first two buckets include minor changes to material or threads while the last two are for major design changes or a product that is so significantly different that it is considered a new product. Changes are sent to engineering, which then builds a representative bill of materials to reflect the changes and estimates the time and cost for making those changes. Quotes are good for a specified period of time and the delivery date is re-confirmed once a firm order is placed. Manufacturing engineering and shop floor planning use the incoming orders to feed the manufacturing resource planning (MRP) system and to complete the initial shop scheduling. New orders are scrutinized to make the final decision on whether to make or buy specific components. The supply chain management is conducted at the buyer level.

The organization that oversees the planning, inventory, warehouse, supply chain and purchasing functions is the planning group. The main concerns at this level are to ensure adequate flexibility is maintained at the shop floor and supplier level through prudent make or buy decisions. Efforts are being made to reduce the part mix within each supplier. The scheduling tools used are based on the capacity of the manufacturing facility. Lead times for raw materials have been an area of increasing focus for this organization. With the rising costs of many exotic materials and the increasing lead-times, it has become more imperative to have accurate forecasts that allow the company to act proactively instead of reactively to control costs. This is not limited to the oilfield services sector as many other industries such as aerospace and even some high-end automotive products must also have more accurate forecasts.

Once the products have entered the manufacturing cycle, the liaison between manufacturing and the design engineers is the sustaining engineering group. This group is responsible for keeping the drawings up to date, correcting any errors and determining the manufacturability of the parts. Another directive for this group surrounds documenting the processes that are used, developing standard work instructions and analyzing new tooling and fixtures for installation in the factory. Under the purview of the sustaining group is a smaller group of people that build the precise bill of materials, create the machine routing instructions for the factory flow and write the computer numerical control (CNC) programs that are used to run the machines. An interesting interaction occurs when parts are moved from one machine to another machine with equivalent abilities. The activities in the planning organization effectively end their control of the schedules once the actual work orders are released to the shop floor and work begins on transforming metal into product.

Once past this point the production control group controls the scheduling of machines and the path of the product through the manufacturing process. The inspection group checks the parts for conformance to the engineering drawings during production. This organization has been transitioning from a separate stand-alone area to one that is more integrated with the machine work areas. This should allow for inspection immediately after machining is complete and before moving onto the next stage of production. As a result, rework can be more effectively traced to the source and actions can be taken to prevent the same error from reoccurring. The products that the Schlumberger Texas facility manufactures have very tight tolerances and much of the inspection work that is done is moving from a manual process to one that utilizes coordinate measuring machines (CMM). These machines can more accurately determine if a part meets the drawing specifications. But while they can measure features more accurately than the drawings require, the extra data is useful in helping to improve process capability. The customer may be involved in quality checks for parts that have quality control plans (QCP) attached to them. QCPs identify quality control steps in the processing of the product. They are requirements such as witnessing of operations and documentation that are more detailed than the specifications and requirements that Schlumberger uses in their engineering definition of the parts. During this stage of production the parts are assembled and tested to ensure they meet all of the requirements. Parts that have QCPs attached to them are held up during the assembly and testing operations to wait for a customer representative to arrive and witness that the assembly operation or test operation does meet the requirements specified in the drawing and assembly/ test procedures.

Quality assurance differs from the inspection function in that they are responsible for putting together the book of data that serves as the documentation that all specifications and requirements set forth in the drawing, bill of material and QCP have been met.

Several smaller groups support the rest of the manufacturing operations. The tool crib is responsible for managing the inventory of consumable tools used on the CNC machines and the hand tools that are used in other operations as well as safety equipment and uniforms. The machine maintenance group has been embarking on a journey to transform to a total preventative maintenance (TPM) plan and integrate the maintenance inventory with the rest of the managed inventory. They have been making strides in writing preventative maintenance guides to help the operators keep their machines in shape.

The final stages of operations within the Texas facility are the warehouse and shipping functions which both reside in the warehouse. The niches that the employees fill characterize the work conducted here. The employees here are generally either very inexperienced or have over 6 years of service. The warehouse is located in a different building from the rest of the operations. The group has been trying to create an understanding for all employees of how the warehouse fits with and helps the other departments. They see their customer as the factory and work at improving how their operations affect the factory in terms of raw material issuing and management of scrap material.

In summary the author learned a great deal about the manufacturing processes that are used to produce these extremely high tolerance parts. The high quality work is completed successfully but not without intervention from many people.

The second location the author visited was a facility in Northern Ireland. The focus of the month on location was to develop a more detailed understanding of completed end item tools that are shipped to customers. This detailed understanding required research into the material, machining, processing, dimension, tolerance and quality requirements for many of the products manufactured at the location. This was undertaken by producing a detailed listing of the machine types and supporting processes (e.g. heat treating, coating or thread cutting) required to manufacture these parts.

This part of the author's orientation with the Schlumberger products, facilities and operations began the research that would help shape the definition of the location analysis tool that was the goal of the internship and this thesis. Using the premise that a new facility would be built and that the facility would produce products similar to the ones produced at the Texas and Northern Ireland facility, the author began research into the end item tools. Gathering a representative sample of end item tools that could be manufactured at a new facility was the first step. This was done by requesting product line owners to provide a list of their most popular products and having the internship project supervisor dictate that new products, still under development, would also be considered, resulting in a list of 10 new products that would be analyzed and 22 of the most commonly ordered parts from another product line as the representative sample of parts to be considered for this new facility.

With a list of representative end item tools the next step was to gather the bill of material information for those end items and all of the sub-assemblies and components that are contained in the end items. Relevant information from this analysis included the material types and sizes, the finishes, the thread types, the special processing requirements, the other miscellaneous processing requirements, and the machine routings. The machine routings indicate what type and size of machine is required to perform the specific machining operations. Analysis of these machine requirements and estimates of the future demand for these products leads to an estimate of the type and size of machines that would be required to be placed in a new factory. Once knowledge of the machines is obtained it is possible to determine approximate costs to outfit a new facility. In addition the results indicate many of the types of suppliers that will need to be present or developed in the area surrounding any new facility. While this information is useful when conducting a qualitative analysis of several locations, the real benefit comes when it is time to build a capital asset request. Detailed financial information is essential to the validity of this request.

Learning about the existing facility processes, the different organizations they must interact with to successfully operate such a facility, the details of the components that make up the end item deliverable tools, and the areas for improvement, was a beneficial exercise to undertake before embarking on the research for developing a tool that will be used to analyze a potential future facility location. The knowledge gained indicated important areas to emphasize within the existing Schlumberger location analysis tools and areas that would need to be enhanced.

3.2. Overarching Tool Methodology

3.2.1. Tool Goals and Features

As outlined in Section 1.4 the scope of the tool to be created was not focused on generating a comprehensive list of criteria to be used in location analysis but instead was looking to create a standard methodology for applying the tool; a robust analysis that provided accurate results and increased the features available within the tool. A summary of the major design goals and features appears in the table below.

Tool Design Goal/Feature	Reason for Goal/Feature	Methodology Used to Achieve Goal/Feature
Increase Objectivity	Ensures that multiple stakeholders trust the process and results.	• 3 levels of involvement, with each level "blind" to the results of the other levels.
Adjustable Parameters	Enables discussion and alteration of certain parameters to allow stakeholders to view the resulting changes to analysis and reach consensus on the results.	• 2 levels of input are adjustable, representing the stakeholder views. • Highest level of stakeholder input can be used independent of lower level results or used to weight results. • Risk profile can be adjusted to reflect current stakeholder view of the effects of risk.
Quantified Risk	Enables decision makers to see a more accurate picture of the range of possibilities for locations and eliminates the 1 number comparison of locations.	• Risk is associated with each criteria • Independently determined from the inputs of 2 levels of stakeholder input (i.e. risk is not decided upon by any one individual) • Risk profile is uniformly applied across all criteria.
Standard Methodology	Ensures that location decisions are made in a consistent manner across the company and that improvements to the process are captured and used for future decisions.	• Standard work instructions integrated within the tool.
Robust Calculations/ Analysis	Ensures that results are applicable to the situation under consideration, that they reflect an accurate comparison and that the results are calculated in a consistent way	• Eliminated calculation deficiencies from previous tools. • Applied calculation methods that are widely accepted and make logical sense.

Able to be Adapted, Updated, Edited	Ensures that the tool is not a static device but one intended to be improved upon and that the tool creator does not retain any "tribal knowledge" about the tool or the calculations contained therein.	• Created using MS Excel workbook allows for adjustment of calculations, how features of adjustability were included and formatting of the document.

Table 1: Summary of Tool Design Goals/ Features

The outcome of achieving these design objectives and enhancing the features of the tool is that this tool becomes the objective basis by which discussions can occur to determine the optimal location for a facility. By using the tool to eliminate unreasonable locations, a smaller subset of locations can be analyzed using a comprehensive cost analysis, forecasting the profit and loss of locations for final determination of facility location. Using this qualitative tool before conducting a detailed cost analysis eliminates unnecessary time and effort in gathering data on locations that will not prove optimal.

3.2.2. Notional Flow of Information and Involvement

Three levels of involvement are required for use of the location analysis tool (see Figure 1). Each level has separate responsibilities and the results from each of the inputs are separated from each other. The inputs from one level are not visible to those inputting the next level of information. This separation increases the objectivity of the tool because users do not color their judgments or inputs based on what they see inputted by another level. Each level is also intended to have different variability.

Figure 1: Levels of Involvement Requiring Input

The executive level stakeholders are responsible for deciding on the strategic objectives. These executives (or equivalent) have the overarching view of the company strategy. They are aware of the current policies and external factors that are at work in the current environment and the overall product or service strategy. These views are the most static of the inputs. A firm view of the enterprise and the desired future state or architecture will mean that these views do not change dramatically over time. They are the same or similar irrespective of the project and locations under consideration.

While the views of the executive level stakeholders are the most static the project level stakeholders views will be more fluid. Each project will be taken on and viewed as a separate entity. The decision on where to locate a new research and development site compared to a new design center compared to a new manufacturing facility will drive different priorities. These priorities will be reflected in the setting of the importance rating for each criterion. Project level stakeholders with their view of the process, organization, knowledge and information technology requirements as they relate to this specific endeavor will be the most appropriate people to determine the importance of each criterion to the success or failure of a project. While the inputs of the executive level stakeholders and the project level stakeholders are related through the categories that criterion are grouped within, it is important to keep visibility between the two inputs to a minimum. This allows the objectivity to increase through not allowing the importance ratings from project level stakeholders to be colored by the executive level strategic objectives. If it is not possible to have completely separate groups conduct the two evaluations, it is then desirable to conduct the two evaluations at different times and especially important to not refer to previous analysis when formulating inputs for the current analysis.

The last level of input comes from the location specialists. These individuals are the ones responsible for gathering the knowledge and information required in order to rate the attractiveness of each location for the individual criteria. It is even more important that at this level of input the results are not colored by the views represented in the project level stakeholder view. When considering locations where Schlumberger already has a presence, the task of gathering this information may become considerably easier since the locations experts can rely on those already conducting business in the location to provide information on how to rate a location. In locations were there is no company presence, the task becomes more difficult as location experts will need to gather information from similar industries, government or published sources and the level of confidence in the results is lessened.

Information gathered from the three levels of involvement results in five data types, four of which are assumed to be independently determined and one set of data that is dependent on two other sets of data. While the risk profile is considered a set of independently entered data, it is not similar to the other three sets of independent data, as it is not newly considered for each project. Adjusting the risk profile is merely asking the stakeholders to verify that the assumptions indicated by the risk profile still hold true. Ideally the risk profile would not change for every project on which this tool is used, much like the strategic objectives section; it is looked at and modified only if the climate in which the tool is used is significantly different from previous occasions. See Figure 2 for a notional chart of the inputs and the resulting data.

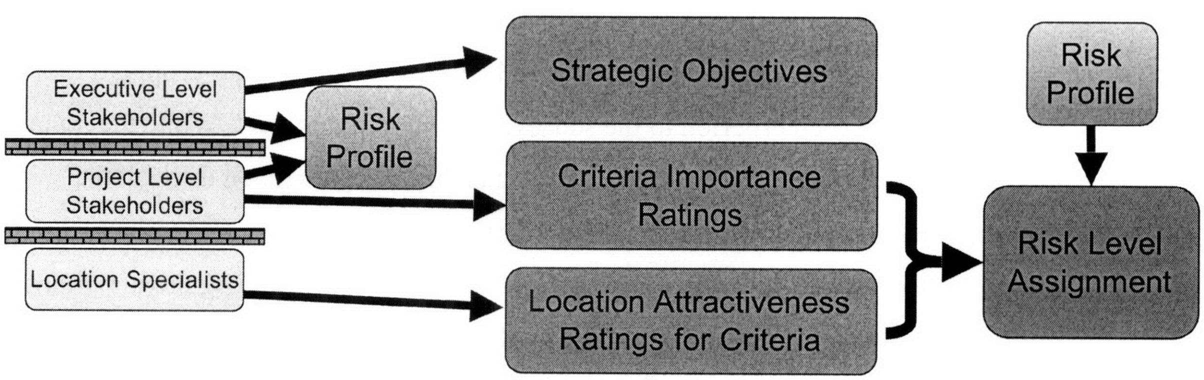

Figure 2: Data Resulting from Inputs

The executive level stakeholders and/or the project level stakeholders verify the risk profile. This verification is not an input of data as much as it is a verification and adjustment of the risk profile if conditions have changed sufficiently to warrant a change. The strategic objectives are a direct result of the executive level stakeholder inputs. The criteria importance ratings are a direct result of the project level stakeholder inputs. Finally, the location attractiveness ratings are a direct result of the location specialists input. The risk assignment level uses the concatenation of the importance and attractiveness ratings to look up and apply the appropriate risk profile level to each criteria. In this way the risk level associated with each criterion is not independently assigned by one level of stakeholder but is the result of the combination of those independent assignments of rating. See Section 3.5 for a more in depth discussion of the risk profile.

3.3. Location Decision Matrix

The actual location decision matrix is contained within a MS Excel workbook as part of an integrated instruction, data gathering, analysis, and charting package. The relevant information from the workbook is summarized in the sections that follow.

3.3.1. Categories

There are nine categories that encompass all of the criteria used as part of this tool, see Table 2 for a complete listing. As previously stated (see Section 1.4.1 for discussion) this is not a complete listing of all possible categories. Categories can and should be added as further research indicates other potentially valuable categories for consideration.

Category	**Description**
Costs – Start Up	One-time costs associated with establishing operations in the new location.
Costs – Ongoing	Costs associated with the location that will be continuous throughout the life of the facility or that will depreciate over time.
Neighboring Industries	Proximity, reliability and quality of required suppliers and supporting industries to the new location.

Accessibility and Logistics	Domestic and international connectivity to the new location, domestic transportation infrastructure and natural disasters in the new location.
Business Infrastructure	Basic business needs such as utilities, land and local government conditions in the new location.
Incentives	Benefits to the company as a result of establishing a new location.
Operating Environment	Local market conditions for the business; local regulatory, political and financial environment.
Social Infrastructure	Includes living conditions, population diversity, community safety and social support networks.
Human Resources	Availability and quality of human resources at the new location for the new facility.

Table 2: Categories Used in the Location Analysis Tool

Each of the categories represents a grouping of unique costs or characteristics that are important to consider in deciding on where to locate a new facility. Depending on the current situation for the company and the desired future architecture the relative importance of each of these categories will vary. Even on a project specific level some of the criteria within each category will be more important and others less important.

3.3.2. Criteria

Within each category there are between five and 23 different criteria that pertain to that category. Each of the individual criteria is aimed at understanding a characteristic of the new location as it pertains to the planned facility expansion. Each criterion plays a role in determining the final score for that category and the overall score for the location. In addition, the ratings that each criterion receives for importance (project level decision) and attractiveness (location specialist decision) will be used to determine the level of risk. While it is acceptable for criteria to have unknown importance or attractiveness, the risk grows accordingly. It is important that new criteria are added as new characteristics or qualities for the facility location decision become apparent. Knowledge gained from each successive location decision should be incorporated into the tool in the form of new criteria. See Appendix A for a listing of all criteria and their associated categories.

3.3.3. Use of Importance and Attractiveness Ratings

Each criteria is evaluated on two dimensions, with each evaluation being conducted by a different level of the decision making process. This dual evaluation process is conducted with each level of involvement not being able to see how the other completed the ratings. This is done for two reasons:

1) To ensure that multiple level of stakeholders have input into the decision making process.
2) To increase the objectivity of the tool and associated analysis.

Both the importance and attractiveness ratings are on a 0-5 scale as shown below:

Score	Importance Definition	Attractiveness Definition
0	Unknown importance	Unknown attractiveness
1	Very Unimportant - The criteria is irrelevant to achieving success in this endeavor.	Very Unattractive - The criterion is unsatisfied and could pose a barrier to success in this endeavor.
2	Unimportant - The criteria is not critical to success of this endeavor, we are still very likely to succeed even without it.	Unattractive - The criteria is unsatisfied in a way that may not allow for success in this endeavor.
3	Neutral - The criteria is not unimportant but it is not critical to the success of the endeavor.	Neutral - The criterion is not unsatisfied but is not satisfied in a way to ensure success in this endeavor.
4	Important - This criteria is critical to the success of this endeavor, success is possible without it but will be more difficult.	Attractive - The criteria is satisfied in a way that will allow for this to be successful.
5	Very Important - This criteria is absolutely critical to the success of this endeavor, with out it success will be very difficult.	Very Attractive - The criteria is satisfied in almost an ideal way to allow this endeavor to be successful.

Table 3: Importance and Attractiveness Scale and Associated Definitions

Importance ratings are designed to give the project level stakeholders input into the facility location decision process by allowing them to rate the importance of each criterion to the success of the project. Project level stakeholders have the view of the project from a much higher level than location experts. These individuals should understand the details of establishing a new facility and be aware of the areas that have caused problems with past projects. They are intimate with the intended use for the new facility and will make judgments as to how each criterion will affect the outcome. However the input of these project level stakeholders should not influence how each individual potential location is judged to satisfy each criterion. Deciding on the importance rating for each criterion in a group setting allows multiple project level stakeholders to have input into the decision process and also encourages dialogue between stakeholders to reach a consensus on how the criteria will affect the ultimate outcome. This helps to increase the objectivity of the tool by eliminating the perception that one person or group was making unilateral decisions that will affect multiple groups.

Attractiveness ratings are designed to be completed by a group of people with experience in evaluating potential locations for possible facility expansion. These are people who are well connected throughout the organization. The job of rating each potential location for how attractively it satisfies each criterion entails being able to pull information from multiple sources and make decisions as to how that information results in an attractiveness score. Ideally this group of people would work with existing groups or organizations within the company who are currently on location in the potential site to develop their attractiveness ratings. If the company has no existing presence in the potential location the task becomes more complicated as the location experts will now have to pull information from government or published sources as well as liaising with companies or organizations that currently do business in the location to gather information that will allow them to successfully complete the attractiveness ratings. The attractiveness ratings are the most subjective part of the analysis and as a result they play a smaller role in deciding the quantitative score that each location receives, however they play an equal role with importance in determining the risk level for each criteria.

3.3.4. How Ratings Determine the Final Score

The importance and attractiveness ratings for each criterion are used to determine the final score for each category and the total score for each location under consideration. After completion of the data collection each criteria has one importance rating and one attractiveness rating associated with it. The importance rating acts as a weight for the attractiveness rating. Previous location analysis tools used within the company multiplied the score by the weighting factor, a decimal value between zero and one, for each criterion. The resulting values for each criterion were summed to achieve the final score for that individual location. Weights did not vary across locations but scores did. This process is very similar to the process described within this thesis with importance substituting for weight and attractiveness substituting for score. However, the prior process had one deficiency in that items with high weight and low score contributed the same amount to the overall score as items with low weight and a high score. For example:

- Criteria A receives a weight of 1 (low) which is multiplied by the received score of 5 (high) and results in a contribution of 5
- Criteria B receives a weight of 5 (high) which is multiplied by the received score of 1 (low) and also results in a contribution of 5

The resulting contribution from both criteria to the total score is identical; however these two cases represent very different situations and should be distinguished from each other. Criteria A represents a situation in which the criteria is not very important for success of the project, however the location under consideration satisfies this criteria very well, receiving the highest score. While it is beneficial for the location to have scored well, this criterion is unimportant to the extent that it doesn't matter to the company what the rating is and that it shouldn't contribute very much to the overall score. In the second case criteria B represents a factor that has received the highest weight indicating that it is extremely important for the success of this project while the location does not satisfy this criterion at all, receiving the lowest score. This is a situation where a criterion was found to be of the utmost importance to the project and the location has scored terribly low, indicating that this is a situation that has the potential to cause problems for the ultimate success of the project and should be reflected as such in the overall score.

The goal is to keep the ratings system simple and easy for users to understand but this deficiency must be rectified. The path chosen by the author was to square the importance rating for each criterion before multiplying by the attractiveness score. This squaring of the importance rating now increases the influence of that criterion toward the final score for the category to a greater extent than the attractiveness rating. As the importance of a criterion increases from 1 to 5 it also gives those criterion with greater importance greater influence. If the two cases are examined again using this new algorithm:

- Criteria A receives a weight of 1 (low) which is squared and multiplied by the received score of 5 (high) and results in a contribution of 5
- Criteria B receives a weight of 5 (high) which is squared and multiplied by the received score of 1 (low) and results in a contribution of 25

Using this method for calculating the scores for each individual criterion, the result is 36 different possible combinations of the 0 to 5 importance scale and the 0 to 5 attractiveness scale. The highest possible score is 125 and the lowest possible score is 0.

Results for every criterion within a category are summed and then normalized, divided by the number of questions in the category, to allow for cross category comparison. This allows decision makers and stakeholders to look at the scores for each category and see which categories represent assets to the project and which represent liabilities across the locations under consideration. The normalization of the categories can be toggled on or off within the tool in order to see the absolute scores for the category and aid in comparing locations on a category by category basis without the effects of normalization.

The final score for each location is the sum of the score for each category. This represents the total contribution of each criterion toward the final representation of the location. At this level the scores can be scaled with the results of the executive level stakeholder analysis. This allows the results of the executive level stakeholder analysis to influence the final results. Once again this is a feature that can be toggled on or off within the tool. Toggling the feature on or off allows viewing of the raw scores and eliminates the reduction in variation caused through the scaling of the final scores. The executive stakeholder objectives indicate the relative weight or priority of each category, to overarching view of the company strategy, current policies and external factors that are at work in the current environment and the overall product or service strategy. These relative weights of the categories can be used in conjunction with the lower level analysis or as a stand-alone guidepost for informing final decisions.

3.4. Analytical Hierarchy Process

Analytical hierarchy process (AHP) is the process that is used to determine the relative weights of the categories. This weighting leads to a prioritization of the categories representing the overarching view that the executive level stakeholders possess of the company strategy, current policies, external factors and overall product or service strategy. It has long been used as a way to determine priority and is a reliable decision making tool that yields a result that is consistent.

3.4.1. Discussion of how Analytical Hierarchy Process works

AHP begins by using a list of attributes, in this case the category groups for individual criteria, and making pair-wise comparisons until all attributes have been compared to all other attributes. AHP analysis can be conducted as an individual but is recommended to be conducted in a group setting where all stakeholders agree on the relative importance of one attribute over another. Attribute pair-wise comparison is comprised of deciding the relative importance of one attribute over another on a scale of 1 to 9 and results in a fraction. The scale uses primarily the odd numbers, reserving the even numbers for those occasions when a consensus cannot be reached among participants. The rating scale and resulting fractions are as follows:

Relative Importance	Resulting Fraction
Extremely less than	1/9
Very strongly less than	1/7
Strongly less than	1/5
Moderately less than	1/3
Equal	1/1
Moderately more than	3/1
Strongly more than	5/1
Very strongly more than	7/1
Extremely more than	9/1

Table 4: AHP Relative Importance Definitions

Using the pair-wise comparisons a matrix can be constructed with the attributes listed along the rows and columns resulting in a square matrix. The matrix is read as "attribute in row X is _____ more important that the attribute in row Y", where the fraction occupies the cell where the row and column intersect. The resulting square matrix is a mirror image of itself along the diagonal, with the diagonal representing each attribute compared to its self and is always of equal importance to itself. After the matrix is constructed it is squared and by 1) summing the values in each row, 2) summing to row totals for all rows and 3) dividing each row sum by the sum of all rows solve for the eigenvector representing the weights that can be assigned to each attribute. This process is repeated and the eigenvector of the current iteration matrix is compared to the eigenvector of the previous iteration matrix. As this process is repeated, the difference in the eigenvectors from iteration to iteration will converge to zero if the choices made are consistent. Once this convergence has occurred, you have the correct weights to apply to each attribute that will sum to 100%. If the original choices are inconsistent, the difference between consecutive eigenvectors will not converge toward zero but will instead oscillate between positive and negative numbers around zero. A simple example of consistent decisions is:

1) Attribute A is more important than attribute B
2) Attribute B is more important than attribute C
3) Attribute A is more important than attribute C

While inconsistent decisions, in this simple example, would look like the following:

1) Attribute A is more important than attribute B
2) Attribute B is more important than attribute C
3) Attribute C is more important than attribute A

Once the eigenvector is shown to converge to zero the eigenvector is the relative weight to apply to each attribute by rows. Included within the tool is an automatic mistake proofing check that informs the user if their decisions were consistent or inconsistent. The tool confirms that the convergence is to zero and then indicates that with a color change of a cell within the tool.

3.4.2. Benefits of the Analytical Hierarchy Process

This process provides a very repeatable and reliable method for determining the weight of different criteria. It is a tool that encourages stakeholders to interact and to discuss differences of opinion and work out a consensus decision. It has the added benefit of indicating if the comparisons were made in an inconsistent manner.

3.4.3. Deficiencies of the Analytical Hierarchy Process

The analytical hierarchy process can become very cumbersome as the number of attributes under consideration grows. For example if you are comparing three different attributes you must complete three comparisons and results in a 3x3 square matrix, comparing four attributes requires 6 comparisons and results in a 4x4 square matrix, while comparing nine attributes (such as in using the location decision categories) requires 36 comparisons and results in a 9x9 square matrix. Also because the eigenvector represents relative weights of all attributes the sum is always equal to 1 (or 100%). Thus when you are comparing large number of attributes, the resulting relative weights can become very small on an individual basis. When these weights are used to scale scores, as in the case of the tool designed as part of this thesis, the differences between locations are not as apparent as their un-scaled scores reflect. It is for this reason that weighting the category scores for each location by their strategic objective weight is a choice that the user makes and can be toggled on or off within the tool in order to provide the fullest range of information.

3.5. Risk Profile

One of the key objectives for developing this location decision tool and methodology was to move away from decisions that were based on one number scores and move toward a methodology that would provide a range of possible outcomes for each location. This was accomplished through the association of a risk value with each criterion. Instead of having this risk value be an independently assigned value based on the subjective opinion of location specialists or project stakeholders who may not have the benefit of all information available, it was decided that the risk value would be dependent on the ratings of importance and attractiveness given to each criteria. In the context of this thesis, risk is meant to convey the idea of uncertainty associated with a criterion. This uncertainty could be in either the positive or negative direction, meaning the actual result could be better than we have calculated or it could be worse. This thesis will refer to upside risk, the level to which a criterion could be more positive, and downside risk, the level to which a criterion could represent a more negative situation than calculated, in order to maintain this idea consistently throughout.

3.5.1. Using Importance and Attractiveness to Determine Risk Level

The use of the possible combinations of importance and attractiveness ratings results in 36 unique combinations. This can be represented as a matrix with importance values as the rows and attractiveness values as the columns.

3.5.2. Risk Levels

The next step in determining the risk profile was to determine how many levels of risk should be associated with the possible scores. Qualitatively looking at the combinations shows some interesting patterns. For instance, if a criterion has the highest importance rating, a five, indicating that this criterion is critical for the success of the project and yet the location under consideration only rates a one on the attractiveness, indicating very unattractive, this would represent a situation that has a potentially large downside risk. This downside risk means that if the attractiveness of that location for the criteria cannot be mitigated there is a possibility that the end result could be worse than expected. While on the other hand a location that has a criterion with a rating of four for importance, indicating an important criterion, and a rating of five for attractiveness, indicating a location that satisfies the criterion very attractively, would represent a situation in which there is a possibility of large upside risk. If the criterion can be exploited for the location, the resulting score could be higher than indicated by the raw scoring.

With this spectrum of risk potential in mind it was decided that five levels of risk would be used. The values associated with each level of risk indicate a percentage of the score that would be used to calculate an upper and lower zone of possibility. Each criterion is given one level of risk based on its ratings and risk is applied to the total category score. All positive risk potentials are summed and all negative risk potentials are summed then these numbers are used to calculate the upper and lower bound of possibility for that category.

The five levels of risk used are:

- Significant downside risk
- Mild downside risk
- Neutral risk
- Mild upside risk

- Significant upside risk

3.5.3. Building a Risk Matrix

Once the number of levels of risk was determined, the values, or percentages, to be associated with each level were decided. This was done through observing the ranges that resulted from using different percentages and through discussions with company officials to rationalize the numbers and results. Through discussions it was decided that downside risk was more important than upside risk and thus the percentages associated with the negative risk levels are slightly higher than their counterparts on the positive risk side. This is a conservative stance that has the potential to indicate higher levels of downside risk. However, as knowledge is gained through use of the tool, the number of levels and the percentages associated with the levels can be refined to add additional confidence to the ranges represented. The resulting risk scale and matrix is shown below in Figure 3.

Scale Factor (% gain or loss)	Risk Type and Level	Definition
-8%		Significant downside risk
-5%		Mild downside risk
0%		Nuetral
3%		Mild upside risk
5%		Significant upside risk

		Attractiveness					
		0	1	2	3	4	5
Importance	0	-8%	-8%	-8%	-5%	0%	3%
	1	0%	0%	0%	3%	3%	3%
	2	0%	0%	0%	3%	3%	3%
	3	-5%	-5%	-5%	0%	3%	5%
	4	-8%	-5%	-5%	-5%	0%	5%
	5	-8%	-8%	-8%	-5%	-5%	3%

Figure 3: Risk Levels and Risk Profile Matrix

The assigning of particular risk levels to each combination of importance and attractiveness was the result of conversations with company officials that were familiar with the problems associated with past location decisions and the rationalizing of the definition of each level of importance in concert with the definition of each level of attractiveness. See Table 3 for definitions of the different levels of importance and attractiveness.

3.5.4. Adjustability

Due to the new and untested nature of the risk matrix it is anticipated that the decisions represented in Figure 3 will change as knowledge is gained, strategic objectives change, or projects under consideration change. These changes will be shown as an increase or decrease in risk aversion and the percentage values will change accordingly. In addition, there may be situations that warrant the changing of the risk profile; adjusting one combination of importance and attractiveness rating to a different risk level. The ability to make these adjustments in real time and see the effects on the results is a feature of the tool. This is designed to allow for easy manipulation of the profile as well as adjusting the values.

3.6. Enterprise Architecting

Enterprise architecting is a new field of study within Engineering Systems that can be defined as "Applying a holistic thinking to design, evaluate and select a preferred structure for a future state enterprise to realize its value proposition and desired behaviors"[16]. In this regard it requires a systems approach to thinking about how transformation of the enterprise is to occur (the path to take) in order to progress toward a future state (where the enterprise wants to be). There are many facets of the enterprise that need to be integrated while balancing the needs of multiple stakeholders. This holistic view of the enterprise is similar to any highly networked system that incorporates management processes, lifecycle processes and enabling infrastructure.

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[16] Nightingale, D. & Rhodes, D. (2007). *Enterprise Architecting*. Massachusetts Institute of Technology.

3.6.1. How the Seven Views Are Represented in the Tool

A pictorial representation of the Enterprise Architecture views and interrelationships appears in Figure 4. It shows that there are seven distinct views of the enterprise and to achieve enterprise performance they must be considered collectively rather than individually. The interrelationships show that some views drive other views, some views drive performance through their bi-directional interactions, and other views serve as the performance enablers.

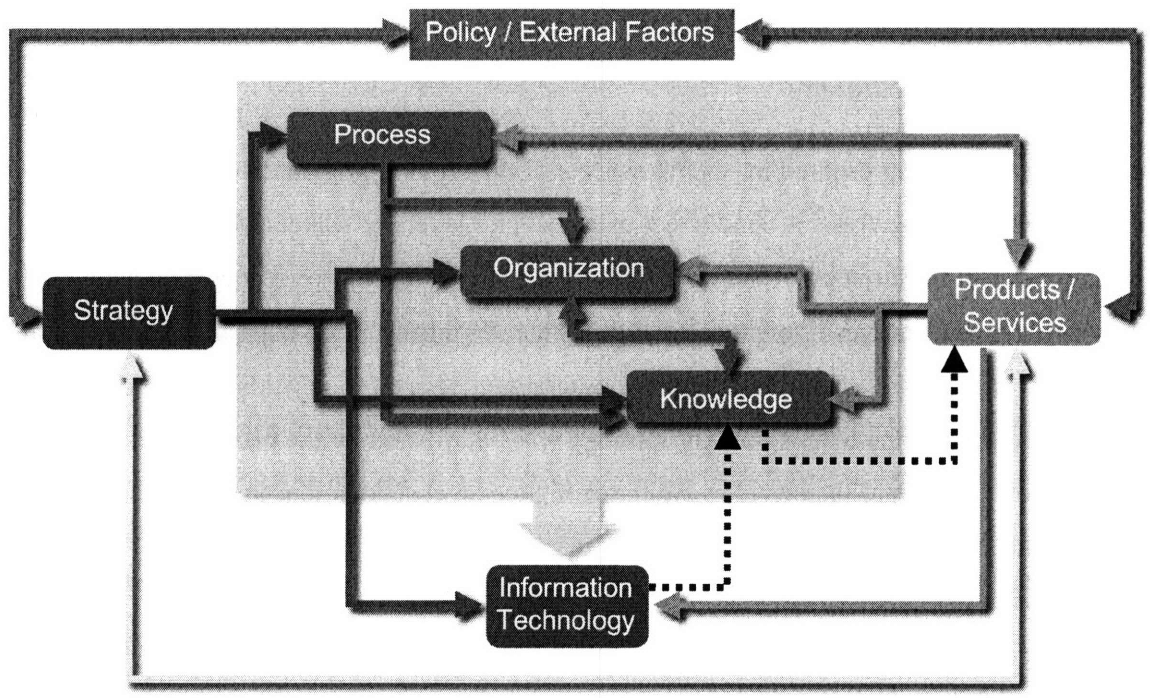

Figure 4: Enterprise Architecture Views Interrelationships[17]

In order to achieve the desired performance of the enterprise there must be alignment across all views and no view can be subordinate to another view. Bringing this enterprise architecture framework into what the facility location decision analysis methodology encompasses ensures that the individual views are represented within the analysis and that the methodology drives the enterprise toward its future state in an integrated manner.[18] The views are represented several

[17] Nightingale, D. & Rhodes, D. (2007). *Enterprise Architecting*. Massachusetts Institute of Technology.

[18] Nightingale, D. & Rhodes, D. (2007). *Enterprise Architecting*. Massachusetts Institute of Technology.

ways within the tool. There are specific criteria that are intended to incorporate each of the views and the specific categories in which they apply. The analysis conducted is also designed to represent all views, not only the extent to which the location satisfies the project criteria, but how it helps to move the enterprise toward it's desired architecture. And finally the process through which the analysis is conducted is designed to provide insight into the effect of the views on the results. Incorporating multiple levels of input help to capture information that represent different perspectives on how the views move the enterprise toward the future state. Each of the views is discussed in more detail in the sections that follow.

3.6.1.1. Strategy

The strategy view is represented in several aspects of the methodology and tool. First, the process by which the analysis is conducted, using several layers of stakeholder input, gathers information about the strategy of the enterprise in regards to the enterprise's current state and also how this project moves it towards the future state. Within the tool, explicit criteria exist that evaluate how this project supports the enterprise strategy. There are questions that take into account and reflect in the results how the strategy will be affected by the product and service views and policy/external factor views. With the higher-level stakeholder input you capture data about how the strategy will impact the process, organization, information technology and knowledge views.

3.6.1.2. Policy and External Factors

Many of the criteria within the tool analyze the policy and external factors that affect the project and how it moves the enterprise forward. These criteria exist within the incentives, business infrastructure, and operating environment categories. Specific external factors such as the support from local government and tax incentives are specifically rated for each location. Other policy and external factor implications that are internal to the company and the future enterprise state desires are implied through the importance ratings for each criterion at the upper stakeholder level. For example, if it is company policy to conduct business in a specific manner, the importance rating of those criteria will reflect that decision.

3.6.1.3. Process

This thesis and tool establish a common process that can be used across the enterprise for evaluating future facility locations. The objectivity, repeatability, reliability and transparency of the tool and methodology provide a framework for designing future processes for the enterprise. By ensuring that importance ratings are completed on a project-by-project basis and that each location is rated against the same criteria, the processes that the company desires to be in place become integral to the project under consideration. Each location will be evaluated on how well it will be able to satisfy these desired processes.

3.6.1.4. Organization

Specific criteria in the human resources, business infrastructure, and operating environment are aimed at how the project will be organized. At the project level, the importance of the desired organizational structure is indicated through the importance ratings of the specific criterion while the local experts undertake the evaluation of each location. For example, if the location will be serving multiple functions, such as engineering, manufacturing and sourcing, the importance ratings would indicate that these skills are very important to the project and each location would be rated accordingly. A pure manufacturing facility may place a lower importance on engineering skills because they are not required for the project.

3.6.1.5. Knowledge

The process of using and improving this tool provides elements of knowledge retention. Applying the methodology of creating standard work, capturing detailed location information, and using common process serves as a model for designing future knowledge retention processes. The knowledge gained during the analysis can be used in future decisions as a way to see how a location has changed over time and by project. In this way, improvements could be made to exclude certain locations or types of locations based on historical evidence that supports the conclusion that it is not a suitable location for the project. This would result in fewer locations being analyzed for each project. Also, as the location specialists become more versed in the criteria, they gain knowledge and can more accurately judge the attractiveness of new locations.

3.6.1.6. Information Technology

Several criteria within the business infrastructure and ongoing costs define the basic need for achieving the information technology needs related to locating a new facility within the larger enterprise network. The tool represents a beginning step toward an integrated tool that is available across the company. Information technology will play a vital role in improving the usability of the tool and the ease with which information is gathered in order to complete an accurate analysis. Once the tool is visible across the company, it becomes easier for different organizations to benchmark the decisions made by their predecessors or to communicate the results with other organizations that may have a need to collaborate in the future.

3.6.1.7. Products and Services

As the tool is designed to locate a facility that will produce products and provide services, this view is one of the main focuses of this thesis. This thesis and the accompanying tool are presented to demonstrate how design of a tool and methodology can indicate the path, or location, that should be taken in order to move the enterprise toward the future state represented by this view. However, since all of the views are integrated and have an effect on the architecture of the enterprise, this view is not superior to the other views. It is the main decision problem that this thesis intends to solve: How to decide on a location to expand capacity for products and/or services?

4. Results

Four countries representing potential locations for a new manufacturing facility for Schlumberger's Completions product line were analyzed as part of a proof of concept test for the methodology and the associated location selection tool. These countries will be referred to as countries Alpha, Beta, Gamma and Delta. The process of choosing to build a new facility and deciding where to locate such a facility is inherently a long process. Because the process could not be followed from start to finish, the internship and research associated with this thesis is based on this proof of concept activity. Due to the limited length of time the author was able to spend with the company, tool development and research were happening concurrently with country analysis. This posed difficulty in not being able to re-conduct analyses once decisions were made about the methodology and the tool, such as increasing objectivity by having three layers of input that are separated from one another.

4.1. Overall Results

Looking at all of the data, with strategic objective weighting turned off, showed that two countries, Alpha and Delta, scored well above the other countries. The analysis recommends that these two locations be looked at in more detail and quantitative analysis performed to indicate the final location decision. The final score for Alpha was 357 and for Delta, 360. The risk band for Alpha ranged from a low of 334 to a high of 386 while for Delta this band ranged from 340 to 391. The only overlap between these top two countries and the lower two countries occurred between the potential downside risk value of 334 for Alpha and the potential upside risk for Beta of 337. These results are reflected in Figure 5. Overall results can also be graphed on a category-by-category basis, showing which locations scored well in each category and which categories scored weaker. The risk bands are eliminated in this view to keep the graph easy to read. This, used in conjunction with the strategic objective weights, provides insight into which locations scored well in the categories that have the highest weights. The results are shown in Figure 5 and Figure 6.

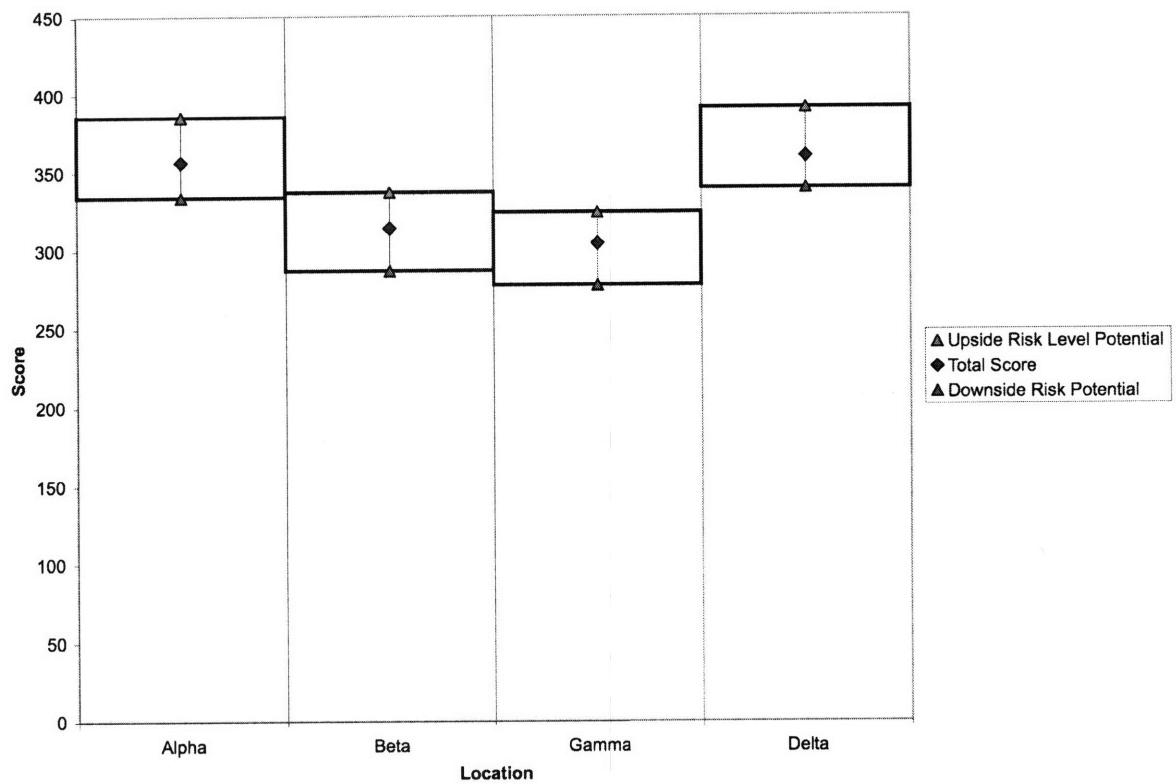

Figure 5: Overall Results by Location

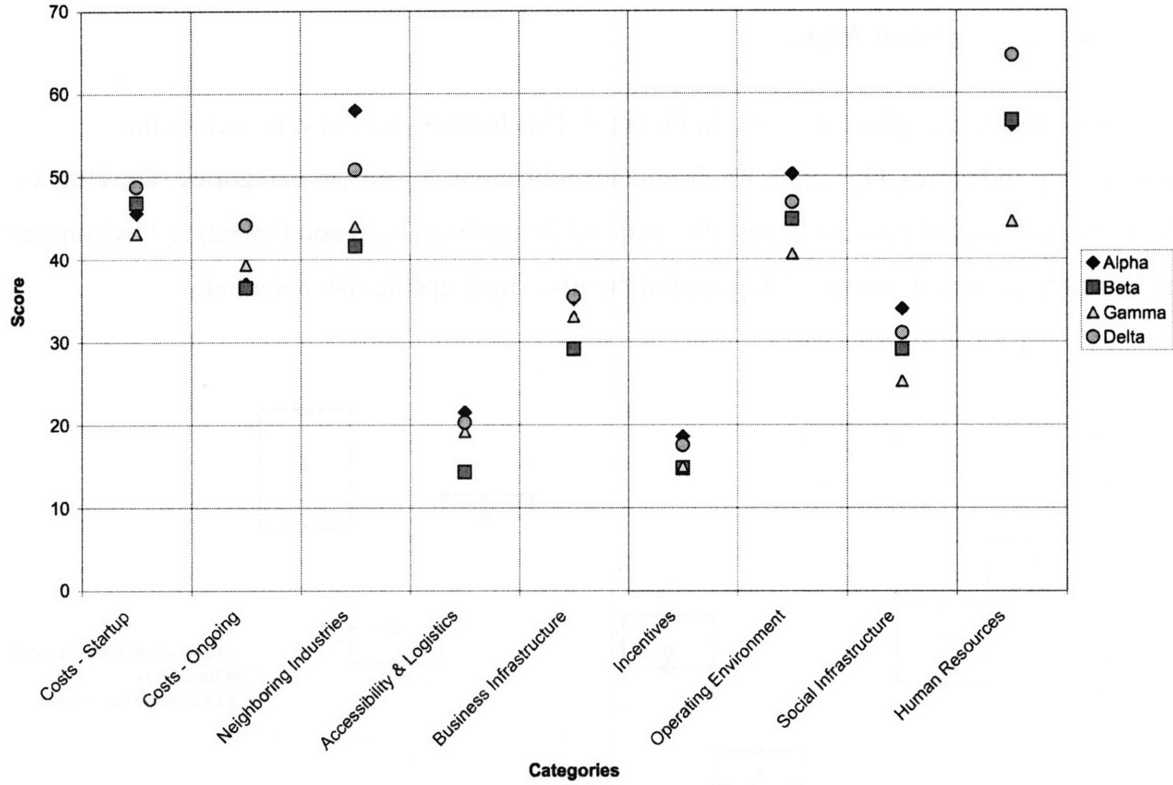

Figure 6: Overall Scores for Each Location by Category

4.2. Location Specific Results

The tool also provides the ability to look at the results for each individual location analyzed. This allows more detail to be seen regarding the scores for each category. In these results, category normalization is turned on so that each category's results are shown on the same scale.

4.2.1. Location Alpha

Results for location Alpha are shown in Figure 7. This location scored very well in the Neighboring Industries, Operating Environment and Human Resources categories. The Human Resources category shows the largest risk band while the Incentives and Operating Environment categories have zero downside risk potential but also small upside risk potential.

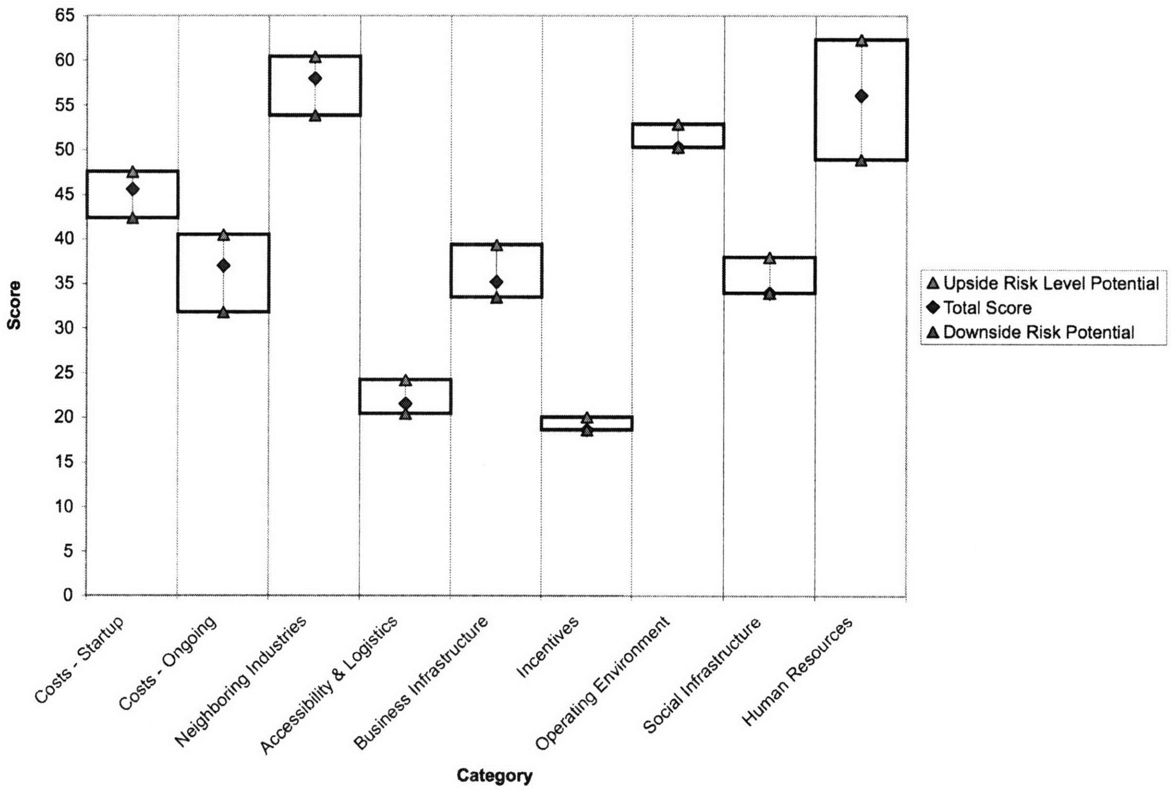

Figure 7: Results for Location Alpha by Category

4.2.2. Location Beta

Results for location Beta are shown in Figure 8. This location scored very well in the Human Resources category. The Human Resources category shows the largest risk band while the Incentives and Accessibility and Logistics categories have the smallest risk potential. Incentives have zero downside risk potential but also small upside risk potential and Accessibility and Logistics have small upside and downside risk potential.

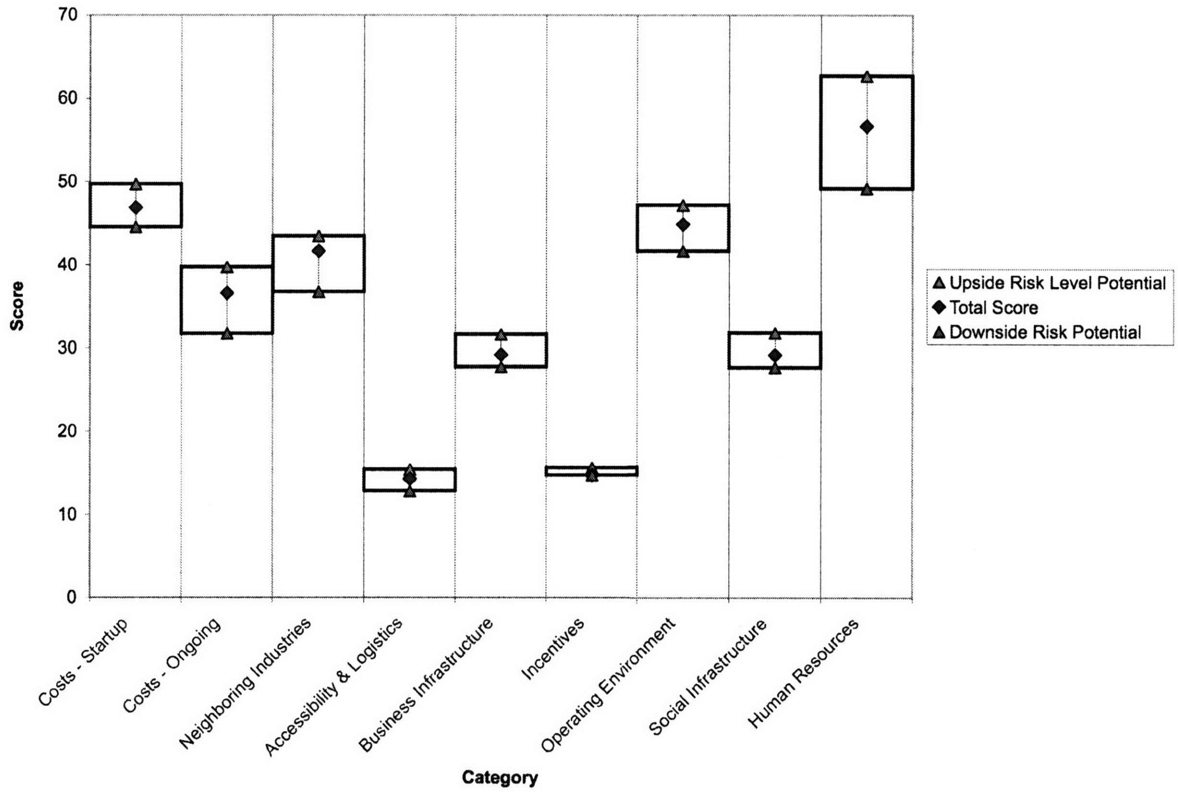

Figure 8: Results for Location Beta by Category

4.2.3. Location Gamma

This location was the lowest overall scoring of the four countries. While this location is consistent with 6 of 9 categories in the 33-44 range, 5 of these scores are the lowest or 2nd lowest out of all locations analyzed. Results for location Gamma are shown in Figure 9.

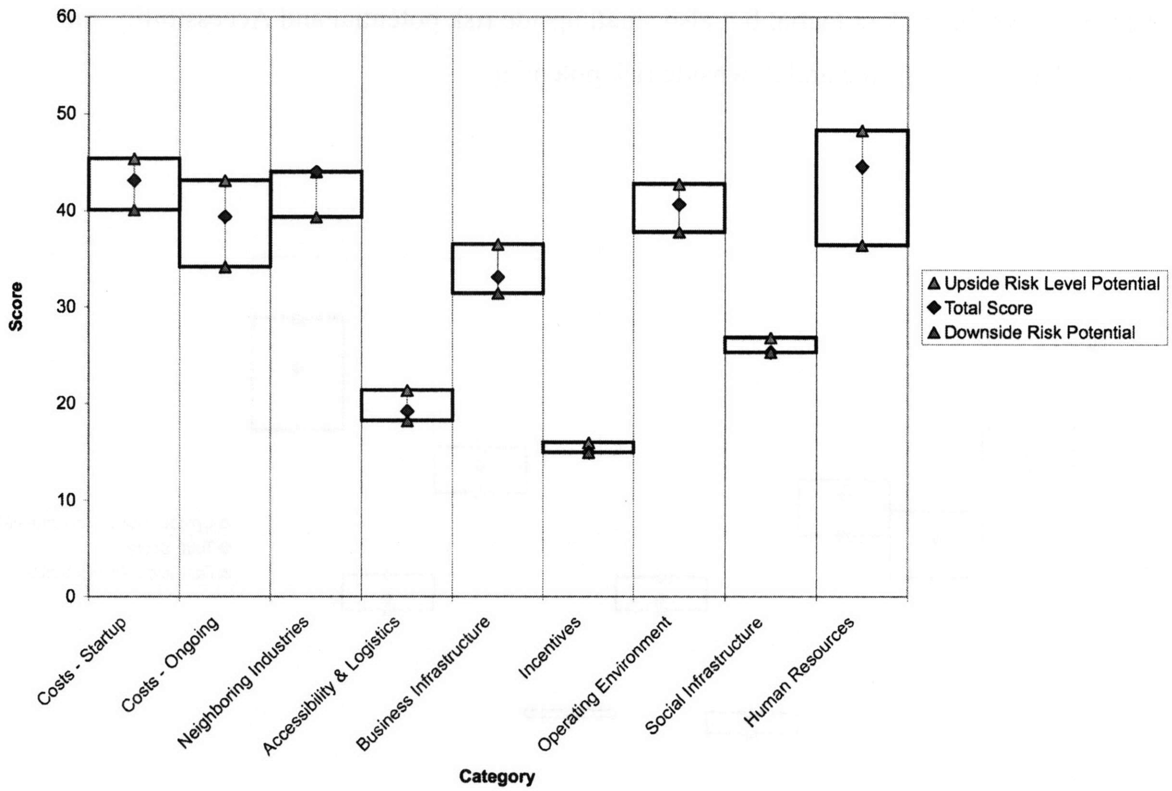

Figure 9: Results for Location Gamma by Category

4.2.4. Location Delta

Location Delta scored very well, with the highest or 2nd highest score in all 9 categories. The four lowest scoring categories also show little to no downside risk potential. Results for location Delta can be seen in Figure 10.

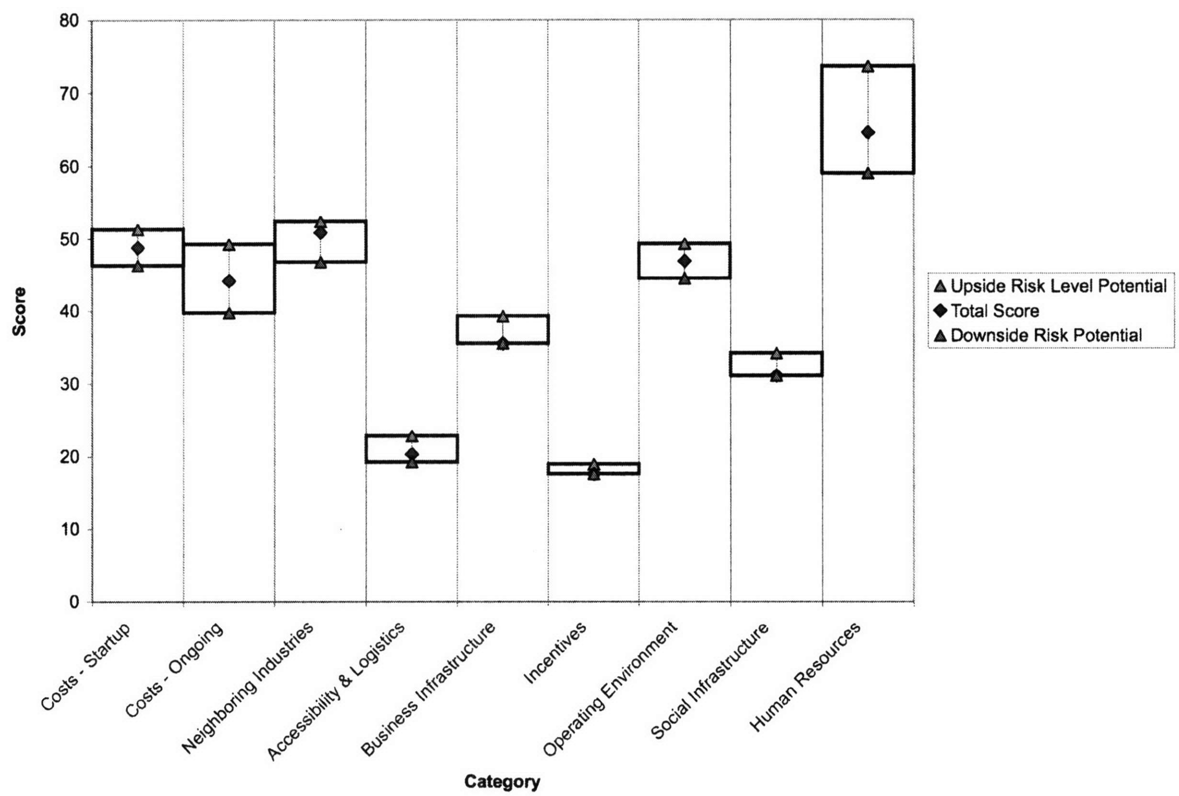

Figure 10: Results for Location Delta by Category

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5. Discussion

This section will discuss in more detail the conclusions that can be drawn from the results.

5.1. *Major Patterns, Relationships, Trends and Generalizations*

Even though the scores are normalized at the category level to provide the ability to compare across categories, it is apparent that the heavy influence of the importance rating to the overall category score plays a role in understanding the results at the category level. If you look at the average importance rating for the category, several generalizations can be drawn:

- Those categories with the highest average importance ranking show the highest scores
- Those categories with the highest average importance ranking show the largest spread of scores between locations analyzed
- Those categories with the highest average importance ranking show the greatest range of risk
- Those categories with low average importance ranking show the lowest scores
- Categories with a high quantity of questions show a greater range of risk potential

The highest scoring location, Delta, was the highest or second highest scoring in each category indicating that a consistent level of attractiveness across all categories is the best candidate for the future facility. However, the second highest scoring location had three categories in which it ranked third in scoring but in the category with the highest average importance level, Neighboring Industries scored well above all other possibilities. This leads to the conclusion that while consistency is important, impressive results are possible from locations that excel in areas that are very important to the project under consideration.

5.2. *How the Results Help in Making a More Strategic Location Decision*

The results, from the strategic objective weighting to the category and location specific, give a clear indication of the locations that are the most likely to provide a satisfactory solution to the project under consideration in a relative sense. The risk bands inform the decision makers of areas of potential overlap between locations. Viewing the data through multiple lenses allows decision makers to align the strategic objectives with the location that best satisfies them. Understanding the future state of the enterprise allows the architecture of the enterprise to influence the decision making process. Ensuring that all seven enterprise architecting views are taken into consideration through criteria, categories, levels of input and process, allows decision makers to be confident that decisions made based on the results are moving the enterprise toward the future state using a process that is repeatable, reliable and transparent.

5.3. Interpretation of Results in Context of the Problem Statement

The methodology developed during the research and internship, conducted as part of the Leaders for Manufacturing program, will provide a process and tool that is repeatable, reliable and is able to be improved as additional knowledge is gained. The tool itself provides transparent analysis methods and adjustability to ensure consensus agreement on the results. The process of using the tool is designed to incorporate the inputs of several different levels of stakeholders while still maintaining objectivity of the final results. The risk band analysis provides an indication of the potential outcomes should risky criteria fail to materialize or if criteria can be exploited for additional benefit. This leads to results that are produced from a more objective foundation and provide much more information than a single number comparison of location scores. The seven views of Enterprise Architecting are implicit within the tool and the process of using the tool encourages the consideration of how the proposed facility location project moves the enterprise toward the desired future state

6. Recommendations

The tool and methodology developed as part of the Leaders for Manufacturing program internship with Schlumberger represent a solid foundation of process and qualitative criteria combined with an analysis tool that can be used for identification of the highest potential locations from the many locations under consideration for a new facility project. Further refinements can increase the quantitative elements involved in the analysis. Providing more objective criteria against which judgments can be made will decrease the subjectivity of ratings.

6.1. Directions for Future Investigations on this or Related Topics

Analytical hierarchy process has many applications, one of which is as a way to measure risk relative to other criteria. It would be beneficial to investigate the use of this method as an alternative to the risk profile matrix. Instead of the risk level being associated with the ratings for importance and attractiveness, risk instead would be based on the relative "risky-ness" of each criterion within a category compared to all other criteria within that category. It would provide a weighted listing of each criterion within the category and assign a percentage to each criterion indicating its relative risk compared to the others. AHP can be used in this multi-echelon fashion and then used to rate the "risky-ness" of each category compared to the other criteria. Causes for concern with this method of assessing risk is that because of the large number of comparisons and large matrices that result from a large number of attributes, it could become unwieldy or burdensome on the decision makers. It is recommended that the company put additional effort into defining their enterprise architecture and the desired future state for the company. This definition could provide insight into the strategic growth areas and methodologies. This should include defining a more comprehensive process for conducting analyses of growth areas along the entire value chain, from determining that growth is necessary, through facility ramp-up, to steady state production.

6.2. Tool Refinements

There are several areas in which this tool could be improved. Currently, the tool exists as a Microsoft Excel workbook with separate tabs for instructions, data entry, charting and raw data. This format is cumbersome and still suffers from not being as error proof as it could be. A move toward a relational database programming solution would enhance the analytical and capacity functions while allowing for reduced errors from user confusion due to ambiguity and workarounds. Specific recommendations for tool improvements are described in detail in the following sections.

6.2.1. Category and Criteria Validation

The categories and criteria used are not meant to be a comprehensive listing but rather to be a robust foundation taking into account the important factors in making a facility location decision while incorporating enterprise architecting frameworks. Using the tool to assess the comprehensiveness of the criteria and categories would be a beneficial exercise. Every time the tool and methodology are used to make a location decision and after the process is complete and the facility is functioning, it is recommended that the tool be re-examined in light of what actually occurred during the facility building and start up operations to locate any deficiencies in the tool.

6.2.2. Benchmarking Existing Locations

The rating system for the attractiveness of the criteria is still a subjective judgment by those conducting the analysis. Without objective quantitative measurements and scales, it is difficult to eliminate this subjectivity. Benchmarking of existing facilities is an alternative method that adds context to the ratings scales and incorporates the context of the company's environment, strategy and existing global presence. By benchmarking existing locations and making a determination for each criterion, such as "An attractiveness rating of 5 would be similar to ________ location" would act as an aid to those conducting the ratings and would serve as the basis for common understanding throughout the company. Benchmarking of recently completed facilities, recent enough that there are individuals who can recall what worked well and what did not, could be used to develop a threshold over which a location must score to be considered. In this sense a location not only could be evaluated on its relative scoring compared to other locations under consideration, but also on an absolute scale indicating its position to all locations within the enterprise.

6.2.3. Risk Profile

The risk profile is the unique part of this analysis and methodology that has not been used in conjunction with the other ratings methods in the past. Further refinement is undoubtedly necessary for not only the risk profile but also for the number of risk levels and the values associated with each level. In the proof of concept test conducted as part of this internship, the objectivity of those rating the locations was compromised because multiple levels of information were available and thus may have influenced the rating decisions. This influence combined with a methodology that was still being developed at the time of data gathering, appears to have lead to similar ratings within the same categories. This is evidenced by the similarity of the risk ranges calculated for the same categories but different locations. Further refining the number of levels of risk, the values associated with each level and the overall risk profile, would lead to more differentiated results based on location. Values associated with the risk levels were chosen to indicate where risk existed but had the side effect of summing to extremely large percentages of the total score for the category. It was in this light that the idea of risk pooling, similar to risk pooling within a supply chain or distribution network, was added to smooth the total levels of risk. This was accomplished by squaring the upside risk values within each category, summing them together and then taking the square root of that sum and repeating this process for the downside risk values. The result was the smoothed upside risk potential value above and the smoothed downside risk potential value below the total score for the category. This methodology needs to be tested over time and on actual location decisions. It may be proven that risk pooling is not indicated and thus smaller values should be associated with each risk level and then summed over the entire category.

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Appendix A – Categories and Criteria

Costs - Startup	
Land use right fees	
Necessary land/site improvement costs	
Cost of temporary accomodation	
Office equiment costs	
Other equipment costs (non-depreciable items)	
Initial costs of hiring and training employees:	
	Management
	Staff
	Shop Floor
Costs - Ongoing	
Purchase cost of land	
Estimated increase in purchase cost of land (over 3 years)	
Lease cost of land	
Estimated increase in lease cost of land (over 3 years)	
Construction costs of buildings	
Machine equiment costs (depraciable items)	
Other equipment costs (depreciable items)	
Occupancy costs	
Telecommunications costs	
Estimated increase/decrease in telecommunications costs (over 3 years)	
Cost of power	
Estimated increase in cost of power (over 3 years)	
Other utilities costs	
Labor costs	
	Management
	Staff
	Shop Floor
Annual wage inflation	
Taxes/Levies associated with ongoing operations	
Trasportation costs	
	Raw materials
	Components
	Finished Goods
Neighboring Industries	
Proximity of location to current qualified suppliers	
Proximity of location to support for manufacturing processes (e.g. machine repairs, tooling suppliers, etc.)	
Proximity of location to support for future SLB product lines	
Reliability of local suppliers	
Quality of local suppliers	
Potential to develop local suppliers	
Accessibility & Logistics	
Accessibility of location to home for product, engineering, sourcing, et al	
Accessibility of location to our key facilities	
Proximity of location to our key customers	
Proximity of location to airports	
Domestic air travel connectivity	
International air travel connectivity	
Proximity of location to sea port facilities	
Reliability of the transportation infrastructure (for both people and product tranportation needs)	
Potential to manage an integrated supply chain from this location	
Intra-city road conditions	
Inter-city road conditions	
Availibility of public transportation	
Risk of natural disasters (e.g earthquake, typhoon, volcano, hurricane, etc.)	

Business Infrastructure

Power supply availibility
Power supply reliability
Water supply availability
Water supply reliability
Other utilities/services availibility
Other utilities/services reliability
Access to fully developed industrial estates
Presence of technical training institutes
Presence of manufacturing research centers
Extent of real estate choice
Support from local government
Risk to infrastructure

Incentives

Incentive availibility for site improvement
Availibility of grants and loans
Availibility of utility extensions and rebates
Incentive availibility for training

Availibility of ongoing tax abatements, credits and exemptions

Operating Environment

Local market growth potential
Local business climate
Local regulatory environment
Presence of ethical business practices
Political risk
Financial risk

Social Infrastructure

Population diversity
Existance of non-indigenious population
Quality of educational institutions:
- Schools
- International Schools
- Professional Educational Institutions

Availibility of quality housing
Expatriate living conditions and quality of life
Availibility of social support institutions/clubs
Communal harmony / social unrest
General safety of location (crime rate)

Human Resources

Average education levels of the local talent
Average education levels of the technical, staff and managerial talent
Laws and requlations governing human resources
Local human rights record
Availibility of managerial talent
Attrition rates of / competition for managerial staff
English proficiency of managerial staff
Availibility of technical/engineering talent

Attrition rates of / competition for technical/engineering talent
English proficiency of technical/engineering talent
Availibility of R&D talent
Attrition rates of / competition for R&D talent
English proficiency of R&D talent
Availibility of skilled operational labor
Attrition rates of / competition for skilled operational labor
English proficiency of skilled operational labor
Skills of local operational labor
Labor productivity
Ability to produce high-quality goods
Absence of unions
Flexibility/coorperation of unions

Appendix B – Analytical Hierarchy Process Example

Suppose that the organization is looking to purchase a new piece of equipment and there are five attributes that are considered important but are unsure which of these attributes is truly the most important and which is the least important.

Five Attributes
Color
Size
Ease of Use
Consumption
Capacity

Using the AHP definitions of relative importance you complete a set of pair wise comparisons. This breaks the problem down into one of deciding only how important one single attribute is when compared to another single attribute.

AHP Relative Importance Definitions		
Relative Importance	Resulting Fraction and Decimal Value	
extremely less than	1/9	0.11
very strongly less than	1/7	0.14
strongly less than	1/5	0.20
moderately less than	1/3	0.33
equal	1	1.00
moderately more than	3/1	3.00
strongly more than	5/1	5.00
very strongly more than	7/1	7.00
extremely more than	9/1	9.00

You repeat this process until all attributes have been compared to each other.

AHP Pairwise Comparison Results			
Color	extremely less than	Size	0.1111
Color	very strongly less than	Ease of Use	0.1429
Color	very strongly less than	Consumption	0.1429
Color	very strongly less than	Capacity	0.1429
Size	strongly less than	Ease of Use	0.2000
Size	strongly less than	Consumption	0.2000
Size	strongly less than	Capacity	0.2000
Ease of Use	moderately less than	Consumption	0.3333
Ease of Use	moderately less than	Capacity	0.3333
Consumption	equal	Capacity	1.0000

Once all of the comparisons have been completed you can construct a square matrix that represents these comparisons.

Original Matrix					
	Color	Size	Ease of Use	Consumption	Capacity
Color	1.0000	0.1111	0.1429	0.1429	0.1429
Size	9.0000	1.0000	0.2000	0.2000	0.2000
Ease of Use	7.0000	5.0000	1.0000	0.3333	0.3333
Consumption	7.0000	5.0000	5.0000	1.0000	1.0000
Capacity	7.0000	5.0000	5.0000	1.0000	1.0000

Legend	
	equal to 1 by rule
	result of pairwise comparisons
	equal to the inverse of purple cells by rule

Using matrix algebra this matrix is squared. The rows of the resulting matrix are summed and normalized. Summing all values within matrix and then dividing the individual row sums by the sum of all values within the matrix to normalize them. This normalized sum of the rows is the eigenvector. The eigenvector is unique to the matrix and represents the relative weights that can be assigned to the attributes. The column "row sum" represents the sum of values within that row. The cell "total" represents the sum of all values within the matrix. The column "eigenvector" represents the "row sum" value divided by the "total" value.

Original Matrix Squared (Matrix #2)							
	Color	Size	Ease of Use	Consumption	Capacity	row sum	eigenvector
Color	5.0000	2.3651	1.7365	0.4984	0.4984	10.0984	0.0212
Size	22.2000	5.0000	3.6857	1.9524	1.9524	34.7905	0.0732
Ease of Use	63.6667	14.1111	6.3333	3.0000	3.0000	90.1111	0.1896
Consumption	101.0000	40.7778	17.0000	5.6667	5.6667	170.1111	0.3580
Capacity	101.0000	40.7778	17.0000	5.6667	5.6667	170.1111	0.3580
					total	475.2222	1.0000

In order to determine if the original comparisons were made in a consistent manner we need to repeat this process until the eigenvector does not change between iterations. Once this convergence has occurred we are confidant that we have made our comparisons consistently and that we have the correct relative weights to apply to each attribute.

Original Matrix Squared (Matrix #2)							
	Color	Size	Ease of Use	Consumption	Capacity	row sum	eigenvector
Color	5.0000	2.3651	1.7365	0.4984	0.4984	10.0984	0.0212
Size	22.2000	5.0000	3.6857	1.9524	1.9524	34.7905	0.0732
Ease of Use	63.6667	14.1111	6.3333	3.0000	3.0000	90.1111	0.1896
Consumption	101.0000	40.7778	17.0000	5.6667	5.6667	170.1111	0.3580
Capacity	101.0000	40.7778	17.0000	5.6667	5.6667	170.1111	0.3580
					total	475.2222	1.0000

Matrix #2 Squared (Matrix #3)								
	Color	Size	Ease of Use	Consumption	Capacity	row sum	eigenvector	eig delta
Color	288.7418	88.8032	45.3435	17.9678	17.9678	458.8240	0.0280	
Size	851.0381	288.7418	146.7029	54.0108	54.0108	1394.5043	0.0852	0.0068
Ease of Use	1640.8222	555.1693	304.6783	112.2825	112.2825	2725.2349	0.1664	0.0119
Consumption	3637.2667	1144.7989	626.0159	245.1757	245.1757	5898.4328	0.3602	-0.0232
Capacity	3637.2667	1144.7989	626.0159	245.1757	245.1757	5898.4328	0.3602	0.0022
					total	16375.4289	1.0000	0.0022

Matrix #3 Squared (Matrix #4)								
	Color	Size	Ease of Use	Consumption	Capacity	row sum	eigenvector	eig delta
Color	364054.634	117594.713	62431.658	23886.199	23886.199	591853.403	0.0271	
Size	1125077.168	364054.634	193268.667	73842.890	73842.890	1830086.249	0.0838	-0.0009
Ease of Use	2262970.208	732240.719	389255.659	148735.047	148735.047	3681936.682	0.1687	-0.0013
Consumption	4835217.709	1562450.610	830572.706	317698.043	317698.043	7863637.110	0.3602	0.0022
Capacity	4835217.709	1562450.610	830572.706	317698.043	317698.043	7863637.110	0.3602	0.0000
					total	21831150.55	1.0000	0.0000

Matrix #4 Squared (Matrix #5)								
	Color	Size	Ease of Use	Consumption	Capacity	row sum	eigenvector	eig delta
Color	6.371E+11	2.060E+11	1.094E+11	4.184E+10	4.184E+10	1.036E+12	0.0271	
Size	1.971E+12	6.371E+11	3.385E+11	1.294E+11	1.294E+11	3.205E+12	0.0838	0.0000
Ease of Use	3.967E+12	1.283E+12	6.814E+11	2.605E+11	2.605E+11	6.452E+12	0.1687	0.0000
Consumption	8.470E+12	2.738E+12	1.455E+12	5.563E+11	5.563E+11	1.378E+13	0.3602	0.0000
Capacity	8.470E+12	2.738E+12	1.455E+12	5.563E+11	5.563E+11	1.378E+13	0.3602	0.0000
					total	3.82447E+13	1.0000	0.0000

We can see from the above example that after four iterations the eigenvector has not changed from the previous iteration. The column "eig delta" represents the change in values from the previous iteration. If the original comparisons were not made in a consistent manner this column would never converge to zero, instead it would oscillate at values around zero. In this case we can see from the final eigenvector the following relative weights and ranking for the five attributes under consideration:

Attribute	% Weight	Rank
Color	0.027	#4
Size	0.084	#3
Ease of Use	0.169	#2
Consumption	0.360	#1
Capacity	0.360	#1

The Capacity and Consumption attributes are the most important and each represent 36% of the overall weight for consideration. Ease of use is the next most important and 17% of the weight. Size and color are the least important attributes representing only 8% and 3% respectively of the weight of the decision.