Plant Location Strategies in a Global Network

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Abstract

Companies currently utilize a number of different approaches to making decisions around where to locate factories. This thesis analyzes the specific challenges faced by Polaroid Corporation in making site location decisions for its instant film assembly operation. The methodology used to arrive at this specific set of recommendations, however, can be extended for use by any company. Three main approaches are taken for determining the optimal site locations:

The first approach involves the development of a simplified cost model. This exposes the current cost competitiveness of the sites under consideration. The sites are also evaluated under a variety of scenarios to determine their performance under future variance in exchange rates.

The second analytical method employed is a characteristic matrix. This approach facilitates the inclusion of qualitative factors which may be critical to the performance of the factory. All four of Polaroid's film assembly factories were visited to observe the unique capabilities of the sites. A graphical representation of the sites' proficiency for development activities, low cost manufacturing, and flexible manufacturing is developed.

In the final technique, the strategic trends and decisions of the instant film business are examined. The company is in the midst of a radical shift in product strategy. New products are being positioned on the basis of fashion more than performance. This shift has important implications for the demands placed on the manufacturing organization.

An integrated set of recommendations is synthesized from the results of the three separate approaches. A shift in plant focus from product and market focus to life cycle focus is suggested. The sites with the capabilities and cost structure for the different life cycle roles are identified.

Thesis Advisors:
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1 Introduction

In the midst of a business environment characterized by increasing levels of globalization, corporations are facing even greater challenges in designing their supply chains. Some companies are responding by replacing factories in developed nations with new facilities in low cost developing countries. Other companies are locating factories and suppliers in close proximity to destination markets. While it is easy to copy a competitor's strategy, it is quite difficult to independently determine the optimal location strategy for one's own organization. These decisions involve precise evaluation of potential sites as well as a thorough understanding of the needs of the organizations, both of which can be elusive.

This research details a manufacturing and final assembly factory location strategy developed for Polaroid Corporation's instant film business. Using a variety of techniques, this analysis determined which existing sites offered the lowest cost, the most desired characteristics, and the best strategic capabilities for the future. The synthesis of these results produced a decision model for the optimal location of current and future film products.

1.1 Company overview

Polaroid Corporation based in Cambridge, MA, manufactures imaging products for global consumer and commercial markets. Products range from instant film and cameras to digital imaging systems, conventional film, light polarizing filters and lenses, and holographic films. In 1999, the company grossed $1.98 billion in revenues and netted a profit of $8.7 million. In the 4th quarter alone, however, the company had profits of $28.5 million on revenues of $650 million.

Founded in 1937 by Edwin Land, Polaroid began with a mission to develop light polarization materials and technology. It was in 1944 that Land first envisioned the one-step photographic system that has since become synonymous with the company name. The first version of this product was sold in Boston in 1948.

The instant photographic system continues to be Polaroid's mainstay product. In recent years the company has made investments in medical imaging, lenses for sunglasses, and holographic technology. Unfortunately, these products have experienced little financial success. As a result of the investment in these development projects, the company's performance and cash positions have suffered considerably over the past few years. The core instant film business, however, continues to be very profitable for Polaroid. While still lucrative, growth in this business has stalled in recent years from increasing competition. Together, these factors have lead to a refocus on the core business and the introduction of new products to spur growth. The company's performance in the most recent quarter gives indication that this strategy is succeeding.

1.2 Project description

Polaroid has a number of challenges facing the internal supply chain for film. The mature existing products face excess capacity and projections of flat demand. Although growth is not expected from these products, they will continue to constitute the majority of revenues and profits for some time. The high fixed cost of these products limits the degree to their costs can be reduced. In response, the company must consider more drastic measures for improving the bottom line from these products.

Additionally, Polaroid has greatly increased its rate of new product introduction to rejuvenate growth in the consumer market for instant film. These new products have fundamentally different needs compared to the existing base. They are likely to have shorter life cycles, smaller cumulative volumes, and require steeper volume ramps.

In the midst of these diverse demands, Polaroid must develop a location strategy for its film assembly plants. It is not clear how the existing location strategy based on product family and geography should accommodate the array of new products. Similarly, opportunities for consolidation to eliminate excess capacity of mature products require thorough evaluation of existing sites which offer a variety of cost structures and capabilities. These demands emphasize the need for a standard process for evaluating the value of sites.

This research examines Polaroid's film assembly sites in the context of the demands of the instant film business to determine a methodology for product sourcing. Three different approaches are taken to weigh the cost, site capability, and strategic incentives for producing various products at a given site. By pulling together the results of these three analyses we construct a comprehensive methodology and specific recommendations for Polaroid.

1.3 Starting Point

Within the past three years, two separate efforts have been conducted within Polaroid related to the plant location decision process. In one case, a team examined the possibility of consolidating two sites that were manufacturing the same product. In the second case, all existing sites were evaluated under the scenario of a single global source. A study of the results and processes of these activities highlights the need to establish a standard methodology within the company for evaluating site locations.

In 1998 a team was chartered with evaluating the financial implications of closing down one of two plants producing identical products. The team was first to determine which site offered the better value proposition for continuing as the single global source for these products. The second part of the process was then to determine the costs and savings involved in carrying out the recommendation.

Upon completion, management was dissatisfied with the impetus behind the recommendation selecting which site to close. The most influential factors were tax benefits, proceeds from the sale of land, and costs to layoff the workforce. Although management deemed these to be important factors, they did not feel that a decision should be based solely on this basis. The methodology that would elucidate the optimal choice on a more satisfying basis was not clear, however.

Also in the same general timeframe, another group conducted a more extensive analysis that evaluated all existing film assembly sites. Although this analysis focused primarily on cost, other factors were considered as well. This analysis had been done several times in

the past, but with inconsistent results and methodology. Again, management recognized the need for a standard process for evaluating sites and making location decisions.

1.4 Thesis Organization

This thesis is organized into six chapters:

Chapter 2 provides the critical background knowledge about Polaroid and instant film. In addition, this chapter presents an overview of the existing literature for site location analysis.

Chapter 3 presents the cost model analysis of Polaroid's instant film business. A simplified cost model is used to gain understanding of which sites are the most cost effective sources for which markets and the reasons and implications behind this.

Chapter 4 addresses the location factors which are more qualitative in nature. Each of the four existing sites is analyzed along a number of criteria. A characteristic matrix provides insight into each site's appeal for development, flexible manufacturing, and low cost manufacturing.

Chapter 5 provides a strategic context for the instant film business. This chapter looks at the recent trends in the market demand for instant film and the changing needs of the supply chain.

Chapter 6 integrates the findings from the three perspectives presented in Chapter 3, 4, and 5. A comprehensive recommendation for Polaroid's current situation is given. The final sections critique the methodology used and detail the author's learnings over the course of the research.

2 Background

This chapter provides background information relevant to a detailed understanding of the issues covered in this research. The first section provides an overview of Polaroid's instant film products. The next section describes the internal supply chain for manufacturing instant film. The final section discusses the different approaches taken in industry and academia to make siting decisions for factories.

2.1 Instant Film

2.1.1 Instant Film Products

Polaroid currently has three primary families of instant film products: integral, peel-apart, and pocket. Integral film is the format familiar to most consumers. It is a fully integrated package that is ejected from the camera and develops in any environment. Peel-apart film is more popular in the business and professional markets. It differs from integral film in that the picture is removed from the rest of the developing package roughly 60 seconds after the picture is taken. Pocket film, which was introduced in 1999, uses the same technology as integral film, but in a much smaller format. Pocket film is treated separately in this analysis to emphasize the differences in the market, manufacturing equipment, and manufacturing process for this product compared to integral film.

2.1.2 Integrated Camera/Film System

One of the key characteristics of instant film is its interdependency between the film and the camera in producing a high quality image. The Polaroid photographic system is not a modular design that would allow film and camera from different sources to be used interchangeably. This is evident in the lack of any alternative sources for instant film for use in Polaroid instant cameras. Although the margins on this film are quite large, companies that are not involved in the design and manufacturing of those cameras are not capable of producing a quality image.

The impetus behind this interdependency has been an inability to characterize the critical parameters of the film and camera delivery system. The number of variables involved in

the development process has hindered efforts to extract a few quantifiable measures to define the system. As a result, there is no standard against which product can be compared as it comes off the production line. The quality of instant film is measured by the quality of an image taken using Polaroid cameras, not by independent metrics.

In the face of competition from other integral photographic systems such as Fuji's, Polaroid must address the implications of this interdependency to create high quality images. In both the manufacturing and design phases, there must be strong communication between the film and camera groups. The groups that develop new film formats or manufacture in early stages would ideally have their camera counterparts either co-located at the same site or in near proximity.

2.1.3 Film Components

Polaroid's instant film consists of three main components: negative, positive, and reagent. The negative takes a copy of the image during exposure. This image is then developed by the reagent chemicals, resulting in a final print on the positive film. In the case of peel-apart film, the positive is removed from the negative and reagent materials after the developing step. For integral film, the print is part of the "integral" package containing all three components, which remains intact. Figure 1 shows the layered assembly process of the three components. The reagent is sealed into pods, which are burst as the picture is ejected from the camera, allowing the reagent, or developer, to spread over the entire exposed region.

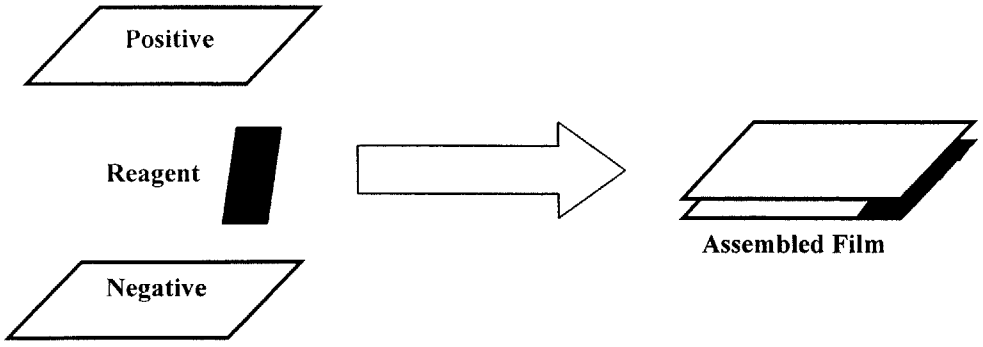

Figure 1. Film Component Assembly

All three components are based on unique chemistries that together create the instant film technology. Although Polaroid sold over 150 million packs of instant film in 1999, the volume of negative, positive, and reagent that went into those packs is small compared to the volumes commonly associated with chemical and coating processes. The combination of volume and unique chemistry have required Polaroid to manufacture these components internally, resulting in a vertically integrated organization.

In order to take advantage of economies of scale in the coating and chemical processes, the company has established factories that produce the entire demand of base chemicals, negative, and positive. Chemical Operations, which produces the base chemicals for the negative and positive coating processes, and for reagent mixing, has a single facility in the Boston area. The positive and negative components are manufactured just south of Boston, in neighboring facilities. The reagent process is less scale-intensive than the other processes, consisting mostly of batch mixing of specialty chemicals. For this component, Polaroid has two facilities: one at the US site, and another at the Netherlands site.

2.1.4 Film Assembly Process

The assembly process for the integral and peel-apart formats uses a web-based technology with highly automated machines. Rolls of negative, positive, and base material continuous strips are unwound through the machine, aligned into proper layers, and cut to form individual frames. Other materials such as reagent pods, plastic light-tight packages, and metal springs are fed into the machine from a peripheral area. The assembly machine is light-tight to prevent exposure of the negative. Since the assembly occurs in the internal area of the machine, it is essentially a large "black box" that spits out a constant stream of film packs.

The assembly machines are able to achieve high output rates through the web-based process. The alignment and timing control needed with this process demands strict mechanical precision. Designing such a high level of precision into the machines comes at the cost of flexibility. For this reason, changes in the physical dimensions of the product require a new set of equipment for manufacturing. Although one site has developed

machine flexibility for products that differ in size along only one dimension, this up front cost has been a barrier to innovation.

2.1.5 Supply Chain

Polaroid has four film assembly sites worldwide, located in Waltham, MA; Queretero, Mexico; Enschede, Netherlands; and Vale of Leven, Scotland. The US and Enschede plants make integral film, while the Mexico and Scotland sites make peel-apart film. The US, Mexico, and Scotland sites manufacture the new pocket film. Figure 2 shows the geographic locations of these sites.

Figure 2. Film Assembly Sites

As mentioned earlier, Polaroid manufactures many of the components of instant film internally. Most of these factories are located in the Boston area. Reagent is the only exception, with one source in the Boston area and the other in the Netherlands. The majority of components for the Scotland and Netherlands sites must thus be shipped across the Atlantic, while the Mexico site received its supplies from the Boston area over land.

The supply chain for 3rd party materials is a relatively small part of the overall supply chain. Most third party supplies are commodity materials such as steel, polyethylene pellets, and packaging material. All of the plants source these materials locally except for Mexico, which uses the same suppliers as the US.

On the distribution side, any of the four sites are theoretically capable of supplying any market. Polaroid's film is truly a universal product. The only customization that occurs is at the packaging stage, which varies for language and promotions. With proper packaging therefore, film can be sourced from any site at which the equipment for that product has been installed. By utilizing its two major distribution centers, located in the US and Netherlands, Polaroid is moving toward a packaging postponement strategy. Product from the US and Mexico sites is shipped to the US center while the Scotland and Netherlands sites ship to the Dutch center. With global demand aggregated to these two DC's, Polaroid can customize packaging at the DC to minimize inventory. More details on the challenges facing the supply chain are outlined by Abbott Weiss, Polaroid's vice president of worldwide logistics[1].

2.2 Overview of Site Decision Processes

In recent years, supply chain design and supply chain management have garnered significant attention in industry. A well-developed breadth of knowledge has been developed by many authors, including Fine[2], and Poirier[3]. A whole host of software now exists as well to help manage purchasing, manufacturing, and distribution logistics. Even with all of this development, however, literature and technology in support of the plant location decision is quite sparse.

Companies currently face a number of different choices in approaching plant location decisions. They can conduct the analysis internally, or hire a consulting company to offer a set of recommendations. In either case, the analytical process used to determine the optimal locations for manufacturing is undefined. The complexity and long term implications of these decisions obstruct the establishment of a standard process. For this reason, stories of siting decisions based on proximity to management's favorite golf course or vacation spot are common. Whether true or not, such stories emphasize the lack of clear procedures for making location decisions.

The remainder of this chapter provides an overview of the public literature on the three most prominent methods for making site location decisions: cost models, characteristic matrices, and strategic analysis.

2.2.1 Cost Models

Many different logistical models exist for identifying the lowest cost solution for a given set of demands and capacities. These models fall into three general groups: static, dynamic, and stochastic. Owen and Daskin[4] provide a review of the existing approaches and literature.

Static models collect data at a single point in time, and determine the optimal solution for that situation. These models are fairly straightforward but can have a wide range of complexity depending on the level of detail desired. Because they incorporate data from a single snapshot, the results of these modes should not be used to make decisions with long term implications. They do, however, provide valuable insight into the present cost structure of sites and can provide a basis for shorter term decisions such as product allocation. Both Crocker[5] and Cerny and Bartmess[6,7] developed detailed static cost models to assist in product sourcing decisions outside the context of opening or closing facilities.

Dynamic models extend the static models to include changes in demand, facilities, and costs in future years. These models then solve for the optimal sourcing strategy for the entire period under consideration. Extending the time frame desensitizes the decision and provides a more robust solution. Unfortunately, most dynamic models are computationally intractable.

Whereas dynamic models have specified data for future years, stochastic models incorporate variation into the model. The magnitude of uncertainty associated with basing long term decisions based on current data is quite intimidating. Stochastic models use probability distributions or scenario planning to evaluate solutions under a variety of potential future situations. By evaluating a range of potential future changes, the model can identify a robust solution that offers the best average performance. Eppen, Martin, and Schrage[8] took such an approach in analyzing an assembly location for General Motors. This type of model is much more appropriate for site location decisions. Only a finite number of future scenarios can be modeled, however, so this approach is always susceptible to future development which were not evaluated against the solution.

2.2.2 Characteristic Matrices

Several of the determining factors of a site's performance cannot be elucidated from a cost analysis. The site to site differences in performance can often be attributed to intangible or more qualitative factors. For example, Porter[9] highlighted the value of locating in industry clusters. Similarly, Mody, Suri, and Sanders[10] evaluated the importance of advanced manufacturing practices in developed countries, newly industrialized nations, and less developed countries. Characteristic matrices offer a method for analyzing sites along these criteria.

Characteristic matrices start with a list of factors that are critical to the analysis. The number of factors can range anywhere from ten to hundreds. Some may be evaluated on subjective 1-5 scales, while others are based on data. Each factor is assigned a weight which can both normalize the data and place greater value to factors which are deemed most important. Each site is evaluated along the list of factors. Data is then normalized and transformed by the weighting factors. Upon completion, the sites with the highest sum total across all weighted factors provide the most favorable conditions for the decision.

Unlike cost models, there exist no classic or standard characteristic matrices. Whereas any factory will have the same sources of costs, factories will differ in the characteristic factors that are important. For example, a stable and inexpensive energy infrastructure is important for a refining operation, but not for a manual assembly process. The factors included in a matrix are thus dependent on the specific nature of the product and company under analysis. As a starting point, however, Brush, Maritan, and Karnani[11] surveyed plant managers to determine the relative importance placed on different location factors. Ulgado[12] also surveyed manufacturing investors with a different set of factors. In general, skilled labor, advanced infrastructure, and market access repeatedly scored high in importance.

Most companies have two sets of characteristics under consideration in the site selection process. One set consists of mandatory requirements, and the other set contains desirable attributes. Within the second set there is likely to be a range of importance such that a hierarchy of tradeoffs exists. Factor weighting schemes in the characteristic matrix can

model this range of desirability with the factors. Yang[13] included such a scheme in her analysis of locations for a Chrysler Greenfield site.

2.2.3 Strategic Analysis

Site locations can also be a source for building strategic capabilities within the organization. The decision to take advantage of low cost labor in a less developed nation or to locate close to customers is often based more on the business needs of the company. For this reason, determining the needs of the organization at the present time as well as in the near future is a critical element of siting strategy. Once the business needs are understood, the skills and capabilities that will best serve these can be identified. Different regions of the world offer a variety of incumbent capabilities and can serve as a key enabler of capability development. Both Ferdows[14] and Bartmess and Cerny[15] evaluate some methods by which companies can use foreign factories to build such capabilities.

Other strategic decisions within the organization can have important implications for siting strategies as well. For example, MacCormack, Newmann, and Rosenfield[16] discuss how the type of manufacturing process employed is a large determinant of the appropriate location. They emphasize that the development of more flexible manufacturing processes are enabling competitive locations in advanced nations close to customers.

Similarly, Verter and Dincer[17] review a number of manufacturing strategies, highlighting the value of integrating the decision processes for facility location, capacity acquisition, and technology selection. Unfortunately, there exists almost no research that addresses such integration. The extensive bodies of research that exist for each of these areas individually continuously treat the other areas as deterministic rather than variable, leaving a rich area for development.

Site location decisions clearly have strategic implications for companies. At this time, however, specific methods for evaluating the strategic value of potential locations remains largely undeveloped. A strong consequence of this unfulfilled need is a prevalence of game theory in location decisions. The frequent observance of multiple competitors in an industry flocking to a given location emphasize the tendency to simply follow the

competition. An internal evaluation of business needs and capabilities, however, can still provide valuable insight into the value of different site location strategies.

3 Cost Modeling

Cost modeling provides a straightforward method for comparing manufacturing locations and making product loading decisions. Here it is used to provide a beginning context for comparing the four instant film sites. These results will be used in conjunction with other methods to give a comprehensive perspective surrounding the site location process.

3.1 Description of Cost Models

As a means for cross-site comparison, cost models offer the most precise level of analysis. The unit production costs, shipping costs, and capacities for each site are gathered. Similarly, the demand for each product is predicted for each individual market. Given these parameters, linear programs can be used to calculate which sites should produce for which markets and in what volume to provide the lowest cost. More complex models can be assembled to give greater detail. For example, breaking out fixed and variable costs provides the opportunity to better calculate the savings of opening or closing facilities or of shifting some percentage of the volume to another site.

Cost models are a useful tool for finding the balance between a strategy of locating facilities in the lowest unit cost area and one of locating close to final markets. Generally, the largest markets are in developed areas which also have higher labor costs. Lower labor cost regions are generally further from the final markets, and as a result incur greater shipping charges. In some cases, intermediate locations may exist and can also be evaluated. For example, US wages are greater than Mexican, which in turn are greater then Chinese. The Mexican option offers both labor costs and shipping costs that are between the extremes of the US and China. Cost models can determine the site that would provide the lowest cost for a given set of demand scenarios and product characteristics.

The greatest challenge in constructing a useful cost model is collecting accurate data. Most product costs in an organization are standard or average costs which include both fixed and variable sources rather than the marginal costs to produce an additional unit. In practice, it is nearly impossible to precisely extract fixed and variable costs from the overall cost structure of a site. As a result, factory loading or capacity utilization has significant effects

on product costs. A highly utilized factory may appear more cost competitive than one with lower utilization when in fact the reverse is true. Thus while cost modeling is very useful, issues with the reliability of data warrant caution when making major decisions such as opening or closing plants.

It is also imperative to note that cost models are inherently static in nature. All of the inputs to the model are defined at a specific moment in time, but in reality are subject to significant variation over time. Small cost changes can usually be accommodated by shifting production to other facilities which currently offer lower cost. Thus maintaining some excess capacity in the factory network can provide flexibility against short term fluctuations. When considering actions with long term implications, such as opening a new plant or closing an existing one, one must realize the static nature of the cost model. Although it is difficult to predict how factors will change in the future, such variation must be considered.

The most common method for incorporating variation and uncertainty into the cost modeling process is through scenario planning. After selecting a solution based on current data, that solution is evaluated under a number of potential scenarios that represent a range of cost, demand, and exchange rate variance. Other potential solutions are likewise evaluated under other scenarios. By comparing the performance of the solution under the current conditions as well as potential future conditions, one has a greater awareness of the implications of any major decision.

3.2 Implications of the International Context

The international context introduces increased levels of uncertainty for cost models. Trade restrictions and exchange rates have considerable effects on delivered costs and are subject to abrupt fluctuations. Shipping rates, which are fairly well defined in the domestic context, become illogical and unpredictable. Similarly to other sources of variation, these factors must be characterized and modeled under potential scenarios.

The formation of large trading blocs has become a significant factor in plant location in recent years. Trade agreements such as NAFTA and the formation of the European Union

have changed the landscape of trade restrictions. Such trading blocs offer tariff-free zones that extend well beyond the boundaries of a single nation. Although the prevalence and magnitude of tariffs are decreasing worldwide, tariffs are still a significant cost factor for many products. The formation of large trading blocs offers companies the opportunity to avoid tariffs for a number of markets with a single factory site. Nevertheless, tariffs are part of international politics and as such, can change quickly and significantly.

In the international context, exchange rates affect every cost that is incurred at a site. Consequently, their impact on the cost competitiveness of a site can be very large. Over the short term, financial hedging tactics can protect a site from small fluctuations in exchange rates. Over the long term, however, the only response to large changes in currency value is to relocate manufacturing. Just as other factors, exchange rates are subject to fluctuation over time. The greater magnitude of changes in exchange rates as well as their unpredictability, however, make the international context extremely challenging for cost models.

Unlike domestic rates, international shipping costs have little correlation with distance, or anything else for that matter. Rather, rates are more dependent on supply and demand. For example, rates from Tokyo to Los Angeles are significantly greater than rates from Los Angeles back to Tokyo. Also, direct shipment is often more expensive than shipment via other routes with longer lead times and distances. Freight rates change frequently in response to both global economic trends and trade patterns. The inability to determine well-defined freight rates must be considered for products with significant shipping costs.

3.3 Polaroid Cost Breakdown

Before entering into the mechanics and results of the cost model, it would be instructive to make some general observations about the cost structure for Polaroid instant film. As an example, the cost structure for Polaroid's US film plant is shown in Figure 3. The US plant does not differ significantly from other sites in its cost structure.

Cost Factor	% of cost
3rd Party Materials	10.0%
Internal Components	56.9%
Yield Loss	1.9%
Total Materials	68.9%
Payroll	20.7%
Depreciation	2.7%
Other	6.9%
Total Labor/Overhead	30.3%
Distribution	0.9%
Total Cost	100%

Figure 3. Polaroid Film Cost Breakdown

A fairly unique aspect of the cost structure for Polaroid's instant film is the large percentage of total cost attributable to internal components. While it is typical for manufacturers to have roughly 65% of cost from materials, these are not usually sourced internally. Almost all of these materials are produced in the Boston area, requiring considerable shipment times for some plant locations.

With two-week shipment times across the Atlantic, a significant amount of raw material can be tied up in transit. Although this does not incur a significant cost for Polaroid, it does create additional variability are require longer lead times. In general, longer lead times can leave a factory prone to larger yield issues due to the amount of material in the pipeline. Polaroid is able to overcome the yield risk from component variability by carefully monitoring through the release process before shipment.

Due to the large percentage of internally sourced components, materials sourced from 3rd party vendors constitute a relatively small part of the cost structure. Figure 3 shows that this percentage is in the vicinity of 10% of total cost. Most of these materials are commodities such as steel, polymers, and packaging. There is little variation in cost across sites for these types of materials.

Distribution costs for the corporation as a whole are roughly 3% of the cost of goods sold. This low percentage is indicative of both Polaroid's success in managing the distribution function and of the high density characteristic of Polaroid's products. Film products, in

particular, benefit from low shipping costs due to the amortization over a large amount of either raw material or finished goods. This low shipping cost ameliorates the potentially costly impact of having internal components all sourced from the Boston area. From the pure perspective of shipping costs, there does not seem to be a large penalty for having multiple dispersed plants.

3.4 Cost Model

Using data collected from within the organization, we constructed a cost model which would determine the optimal loading strategy for the four film factories for achieving lowest cost. The underlying goal of the analysis, however, was not to determine the specific loadings, but rather to gain a sense of which factory locations could serve which markets at the lowest cost. To accomplish this, we made some simplifying assumptions. The first was to aggregate demand for all instant film products in a given region into a single product demand. The second was to similarly combine all existing film capacity at a site into a single, non-product specific capacity value. Capacity is then treated more as an infrastructure or building capacity rather than a machine capacity. The third assumption was to ignore the cost to relocate production based on the results of the model. Together, these assumptions allow for the comparison of all sites, independent from the differentiation created by previous management decisions.

The cost of components and 3rd party materials are fairly consistent for all four sites. Shipping costs also show little variation across sites and markets. As a result, the two greatest sources of variation in cost across the sites are tariffs and labor costs. Product shipped to North America incurs a 4.25% duty, while shipments to the European nations pay a 6.9% duty. These duties are not paid if the product is made by a factory located within one of these regions. Polaroid does not have any film factories in the Asia Pacific or South American regions, and so film from any site incurs a duty of roughly 5%. Labor costs also vary significantly, with Mexico offering the lowest labor, followed by Scotland, Holland, and the US.

The primary source of demand for instant film over the near future is projected to continue to be the US. Slightly over 50% of film volume will be consumed in either the US,

Mexico, or Canada. The rest is split between Europe and Asia, with South America providing relatively small volume. When these numbers are broken out down by the type of film, there are clearly geographic distinctions between the demand for older versus newer formats. However, we will treat demand homogeneously for now and examine the implications of these differences in Chapter 5.

The results of the cost model are shown below in Figure 4. Each entry indicates the volume that a plant should produce and ship to the given market. For example, the model indicates that the Mexico site should manufacture two units for the North American market. In order to protect the interests of the company, specific cost data is not presented, and the results data in Figure 4 have been disguised. General trends, however, can still be gleamed from the disguised results.

		Market Location				
		North America	European Union	Asia Pacific	South America	Plant Capacity
Plant Location	United States	0	0	0	0	25
	Mexico	2	0	0	0	2
	Netherlands	16	0	3	2	25
	Scotland	0	7	3	0	10
	Market Demand	18	7	6	2	

Figure 4. Base Case Cost Model Optimization

The cost model allocates production to plants based on the lowest system cost and are constrained by site capacities. For this reason, markets can not always source product from the lowest cost site. We will now enter into a discussion of the impetus behind the results shown in Figure 4.

Mexico is the lowest cost source for all markets. Due to its limited capacity, however, it only ships product to North American markets. Scotland is the second lowest cost source for all four markets, but it too is limited in capacity. As a result, it serves all of the European demand, and as much of the Asia Pacific demand as possible with remaining capacity. The Holland site provides a lower cost product than the US and consequently serves all remaining demand in North America, Asia Pacific, and South America. In the cost model, the US plant is the highest cost source for all four markets. Since the other

three sites provide enough capacity to serve the global demand, the US site is not needed in this optimization.

In order to incorporate some dynamic variation into the cost model, scenarios with other input costs were analyzed as well. For example, a 20% appreciation of the Dutch guilder produced the results in Figure 5. In this case Mexico and Scotland remain unchanged, but it becomes advantageous to switch the remaining North American demand from the Netherlands plant to the US plant. Thus while the base case may indicate inefficiencies in continuing to operate the US plant, small variation in the future may quickly create a situation which benefits from the US plant location.

		Market Location				
		North America	European Union	Asia Pacific	South America	Plant Capacity
Plant Location	United States	16	0	0	0	25
	Mexico	2	0	0	0	2
	Netherlands	0	0	3	2	25
	Scotland	0	7	3	0	10
	Market Demand	18	7	6	2	

Figure 5. Alternative Case Cost Model Optimization

3.5 Implications for the Future

A large percentage of the cost for instant film is fixed with respect to plant location. Materials represent about 2/3 of the cost, and do not change due to internal sourcing of most non-commodity components. Yield is relatively stable across sites due to the heavily automated manufacturing process. Shipment of both raw materials and finished goods is an extremely small part of total cost, facilitating the use of remote locations. Duties can be a significant cost, but the effect has been reduced in recent years through the establishment of large trading blocs.

Since the greatest source of variance is the cost of labor, the Mexico and Scotland sites offer the lowest cost sourcing options. Recalling that the cost model uses static data, however, it is wise to analyze the susceptibility of these results to changes in exchange rates. Past history is the best, albeit a truly imperfect, indicator of expected future volatility in exchange rates. Figure 6 shows the annual change in the exchange rate of Mexico, Scotland, and the Netherlands against the US dollar over the last 14 years.

At first glance one can clearly see differences between the stability of the Mexican peso against the US dollar and that of the Dutch guilder and British pound. The peso has decreased in value against the dollar for each of the past 15 years. In some years, it has depreciated by as much as 135%. Even the pound and guilder, which are considered relatively stable currencies, saw increases and decreases of 10% or more in multiple years. Currency hedging in financial markets can decrease a company's exposure to short term oscillations in rates. However, if exchange rates shift such that they do not return to their original values for long periods of time, sites may cease to be competitive and require more drastic action.

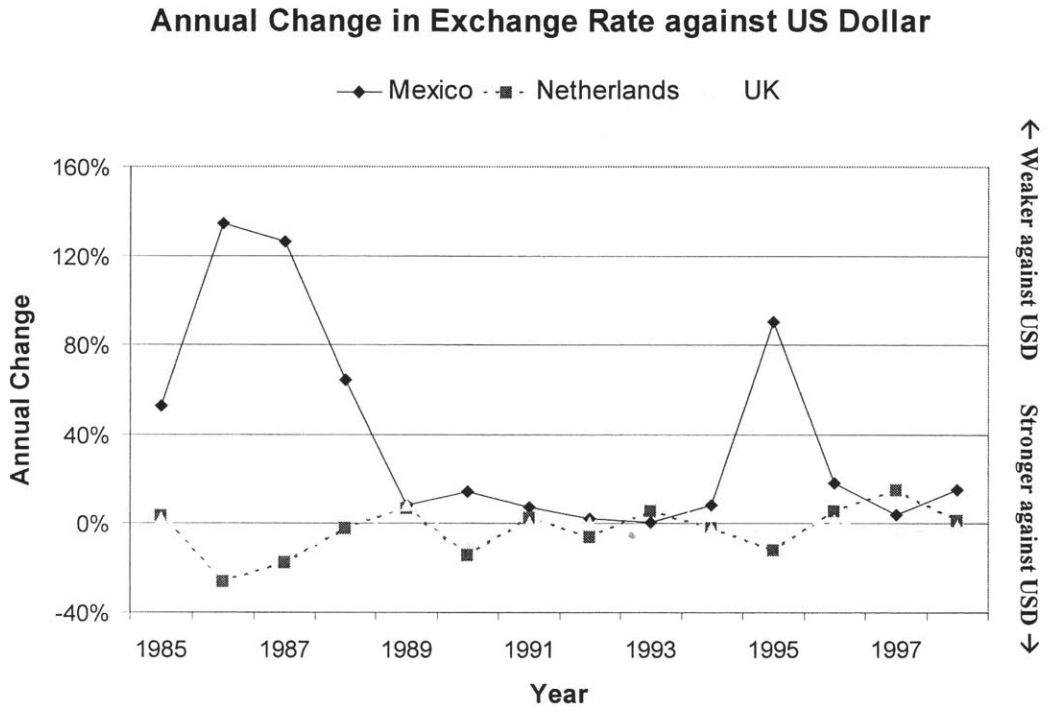

Figure 6. Historic Exchange Rate Fluctuation

The Mexican peso has continued to decrease in value throughout the 1990's. While this has made Mexico even more attractive for low labor cost, there are several factors which might reverse this trend. First, NAFTA has led renewed investment by American companies in Mexico. This may lead to greater economic stability and increased wages that offset the advantageous exchange rates. Additionally, the 1990's were largely characterized by depressed oil prices, which have had a substantial impact on Mexico's currency. Recent increases in the price of oil may reverse this trend, leading to an

appreciated peso. In any case, a company establishing or expanding facilities in Mexico should consider the potential impact of the currency's stability over longer periods of time.

As a means to characterize the sensitivity of the cost model results, the exchange rates that would achieve equal costs were calculated. No single number can be determined due to market-dependent differences in duties and shipping costs. Eliminating these differences, an appreciation of the peso, guilder, and pound by 370%, 40%, and 80%, respectively against the US dollar, would achieve roughly equal costs across sites for Polaroid's instant film assembly.

In summary, our cost model has determined which sites are the lowest cost sources for Polaroid's instant film. Although our simplified analysis ignored the product-specific nature of existing capacity and the cost of equipment relocation, we have a basis for making future decisions for cost minimization. We have also identified the major sources of cost variation and their sensitivity to exchange rates. The degree to which cost is the primary driving force and to which intangible factors are important is still left to be determined.

4 Characteristic Modeling

Because sites are critical in providing capability development as well as cost-efficient production, location decisions need to include more than simplified costs analyses. Every business will have slightly different needs that must be met by a location, of which cost is only one. Characteristic matrices allow factors that are not easily brought into a cost model to be included in an analysis. This chapter uses a characteristic matrix to evaluate these factors and compare how Polaroid's four instant film sites satisfy the demands of the supply chain.

4.1 Site Analyses

In the process of data collection, the author visited each of the four film manufacturing sites. Through plant tours and interviews with local personnel, each site was evaluated along a number of criteria related to its operations and its interfaces with other parts of the organization. This data was then organized into a matrix with appropriate categories. This section provides summaries of the observations made at the sites.

4.1.1 US Site Characteristics

4.1.1.1 Products, Functions

As its original home, the Boston area continues to be the primary location for the majority of Polaroid's operations and employees. The company headquarters are located in Cambridge, MA. Development resources for both film and camera products remain in the area as well. Marketing initiatives are primarily driven from the Boston offices, targeting the large US market.

Almost all of the components for worldwide instant film are manufactured in the Boston area. The entire supply of negative and positive sheet materials, two of the major film components, are processed locally. Batteries and raw chemicals are also exclusively produced by internal groups in the area. The developer chemicals, or reagent, for the US and Mexico sites is manufactured there as well.

The quality of assembled film is highly dependent upon the properties of the component materials. These component materials, however, exhibit significant variation due to their sensitive chemical nature. Once the materials age, their properties tend to stabilize, at which point the variation from batch to batch can be characterized. In order to optimize the final film quality, a group in the Boston area manages the release process, whereby component properties are monitored during the aging period. This group then identifies specific negative, positive, and reagent batches with complimentary properties which are matched together for shipment and assembly. This capability requires considerable skill and experience. Consequently, this group resides close to the component factories and supports all four film assembly sites worldwide.

The US film assembly plant manufactures both the integral film and pocket film formats. The integral film capacity is quite large, nearly enough to serve the entire global demand. The operation has a long history in this facility, established here in the 1970s and still using nearly the same equipment. Pocket film capacity, on the other hand, is quite small. The existing production equipment is largely left over from the recent process development effort, which was done at the US site, and continues to be utilized to help satisfy the upside demand.

4.1.1.2 Workforce – cost, skills, flexibility

The workforce at Polaroid's US film assembly plant is similar to the workforce in all of Polaroid's US facilities. Most employees have been with the company for the majority of their extended careers, have high skill levels, and receive relatively high wages. Having such experienced employees in the factory is especially useful given the high complexity of the assembly equipment. Employees' familiarity with the equipment is useful in troubleshooting and in working within the dark interior where the negative material is exposed prior to completion of the assembly process.

Polaroid has also been able to leverage the high manufacturing skills of the US workforce to establish new manufacturing practices and proliferate them to other sites. For example, the US site has recently pursued aggressive productivity gains on the factory floor. In response to higher labor rates compared to the other assembly sites, the US workforce

made improvements that enabled them to supervise the operation of machines with fewer employees. The US site serves as the leader in many of these improvements which can then be implemented at the other sites. In this way, some of the higher labor cost of the US site is leveraged across all of the manufacturing sites.

4.1.1.3 Supply Chain

As mentioned, the US site is in close proximity to the component manufacturing facilities. On one level, this benefit lowers the need for inventory levels. On another level, however, this also facilitates much more rapid information feedback. Given the highly variable properties of the component materials, such quick feedback is valuable for identifying yield issues and verifying the release process.

Finished goods from the US assembly site are shipped to a local warehouse that serves the North and South American markets. Chapter 3 showed that distribution costs for finished goods was not a big concern, even over longer distances. Nevertheless, having the assembly plant within an hour's drive of the warehouse has significant advantages. Much of the US consumer market for instant film is characterized by promotions which may utilize customized film or specialty packaging. In either case, the proximity of the assembly site to the distribution center enables quicker response to customer demands and reduces exposure to product obsolescence risk.

Polaroid's 3rd party suppliers for the North American sites and its resources for managing those suppliers are located within the US. Due to the unique nature of the product, the 3rd party materials that are not commodities require customization for Polaroid's instant film. Many materials are single sourced to minimize the cost of this customization. The lack of second sources requires active management to ensure consistent supply. Additionally, the sensitive nature of the product stresses high skill levels and expertise in identifying and developing suppliers for new products. The US site is uniquely qualified to meet these demands.

4.1.2 Mexico Site Characteristics

4.1.2.1 Products, Functions

The Mexico site, located in Queretero approximately 50 miles northwest of Mexico City, is the smallest of the four sites. However, it has also been the site of the largest expansion in recent years. This site serves solely as a manufacturing facility, and produces two instant film products: peel-apart film and pocket film.

This site has manufactured peel-apart film for the better part of two decades, albeit in small volumes. The establishment of this site enabled some large contracts with surrounding governments, and originally provided duty relief to some of the markets in Central and South America. Since that time, however, Mexico's trade agreements have changed. The duty advantages to those markets has been lost, but with NAFTA there is no longer a duty for products destined for the US market.

The development of pocket film has led to a much greater investment in the Mexico site. Polaroid has installed roughly 2/3 of its pocket film capacity in this site. Two different manufacturing processes, one manual and the other semi-automated, have been set up in the plant. The manual process is unique to this site, meant to take advantage of the lower labor cost and provide a hedge against equipment issues during the startup phase.

4.1.2.2 Workforce – cost, skills, flexibility

Polaroid's Mexican site is clearly the cost-conscious alternative by virtue of its low labor rates. The average wage at the Mexican site is approximately 20% of the wage at the US site. The employees are not as experienced, however, and this aspect has been exacerbated by the recent site expansion. The lower skills and greater lack of experience result in lower labor productivity as measured by employees per machine. However, the lower labor rates more than make up for the lower productivity to deliver lower total labor content per film pack.

The culture and labor laws of Mexico provide a great deal of flexibility for this site. In many nations, strong labor laws or unions hinder a company's ability to react to changes in demand by laying off employees. However, Mexico offers much greater flexibility in the

workforce. As a result, Polaroid can respond to large demand uncertainty, as with new products like the pocket film, by staffing heavily to provide the flexibility for upside capacity while incurring little downside cost.

Polaroid's Mexico site has had some unique challenges in employing a productive workforce. The unemployment rate in Queretero is quite low, roughly 3%. Although Polaroid has a strong name and appeal within the community, it has been forced to reach further out into the surrounding area to find available labor. Many of the individuals in the surrounding rural area, however, have never been in a modern work environment. In fact, many applicants lack not only technical expertise, but also the hygiene and nutrition habits considered basic in today's environment. In response, Polaroid has created a more comprehensive training program that delivers not only the technical content, but also addresses these unique needs. This program has been pivotal in Polaroid's ability to ramp volume at the site to meet the demand for its pocket film.

4.1.2.3 Supply Chain

One of the major advantages of Mexico in addition to its low labor costs is its proximity to the US. Polaroid's products are not expensive to ship. The real value for Polaroid is derived from the ability of the US knowledge base to lend strong technical support to the Mexico site. The close proximity permits more frequent travel and communication. The shorter supply chain facilitates quicker reaction and information turns.

Components for the Mexico site are shipped from the Boston area over land. Trucks leaving the warehouse in Boston usually arrive in Queretero within the week. Finished goods then return to the Boston warehouse via the same route. Since transit times are consistent, product flow tends to be smooth.

One of the most severe weaknesses of the Queretero location is the lack of a strong local supplier base. As a result, the Mexico site receives all of its 3rd party supplies from the same sources as the US site. Most materials are shipped from the Polaroid warehouse along with the internally-manufactured components. Some recent efforts have focused on consolidation and shipment directly from vendors to prevent double-shipment. Since these

materials constitute only 10% of the product cost and shipping costs are low, the lack of local suppliers does not present a significant issue for this site in the current factory network. If it could no longer receive the supplier management support from the US site, however, the Mexico site would be poorly positioned to do so itself.

4.1.3 Netherlands Site Characteristics

4.1.3.1 Products, Functions

The Netherlands site, in Enschede, was the first manufacturing site established by Polaroid outside the US. It currently produces half of the global demand for integral film, splitting production with the US site. In addition to integral film, the Enschede site is the only site other than the US that has reagent production capability. Polaroid also maintains the second of its two major distribution centers here, as a complement to the US center.

Having reagent production capability at the Enschede site offers the opportunity to serve both the Enschede and Scotland plants from a local proximity. At the time of the decision to add more reagent capacity, having a source for this component outside the US offered greater flexibility for future site location decisions. Additionally, this saves two weeks of reagent inventory versus shipping from the US. As a final benefit, eliminating transatlantic shipments of reagent removes the environmental risk associated with this extremely caustic material. The volumes of film that were projected at the time of this investment have since been reduced, resulting in excess capacity in the reagent area.

Enschede is also home to one of the two major global distribution centers. This DC primarily serves Europe, Africa, and Asia. Having the plant in such close proximity to the DC enables lower inventory levels just as in the US site. Transit times to the DC are small, and there is less risk of obsolescence. Specialty packaging places challenging demands on the plant and DC. Promotional packaging, grouping of multiple film packs together, and packaging cameras and film together are examples of the kinds of special orders that commonly come out of the DC.

4.1.3.2 Workforce – cost, skills, flexibility

Similar to the US site, the Enschede workforce is characterized by high levels of seniority. These experienced employees bring high skill levels to the factory floor. However, they do not have the breadth of experience that many in the US have due to the focus on integral film assembly. Whereas the US site also has component manufacturing, film development, and camera development nearby, the Enschede plant has exclusively focused on integral film.

The cost of labor in the Netherlands plant is slightly lower than in the US. Although the workforce has been less aggressive in achieving productivity improvements, the labor content per pack is still slightly lower. As seen in Chapter 3, however, this difference is within the range of exchange rate fluctuations seen in the past. The strong US dollar has allowed the site to keep its cost advantage even though it is moving more slowly on productivity improvements. In the future this advantage may diminish, in which case the site will be under significant pressure to improve efficiencies.

The Enschede workforce is also characterized by a very strong labor union. Both the culture and the government of this region strongly promote workers' rights. This has placed serious restrictions on management's ability to reduce headcount in response to slowing product demand. The site has begun to utilize a greater number of temporary workers to meet demand seasonally and for highly volatile specialty packaging operations. However, the lack of downside flexibility poses a significant risk of future allocation decisions.

4.1.3.3 Supply Chain

Although the Enschede site manufactures its own reagent, the bulk of the film components are still shipped from the US. Ocean freight transit times across the Atlantic are approximately two weeks. This longer pipeline poses relatively little threat for raw materials. Most are not product specific, and thus show less variability in demand. Yield issues can cause problems, especially since they generally arise at the batch level which is quite large for these raw materials. The infrequency of these yield issues, however, renders the longer transit times low risk and adds little cost to the system.

The Enschede site is a prime location for a distribution center. The area has a historic focus on distribution due to the historic prominence of the Rotterdam port. The site is also geographically centered for access to the entire European market. Since this DC serves Europe, Africa, Asia, and the Middle East, it is beneficial to have an integral film source nearby. Assembled film is highly specific after the packaging step. The extensive promotional packaging that is done for integral film in particular requires careful management of inventory. The Enschede film production thus offers minimal inventory and obsolescence costs for the European, Middle Eastern, and African markets. Product made here for American markets, however needs to be generic or very carefully managed.

4.1.4 Scotland Site Characteristics

4.1.4.1 Products, Functions

The Scotland site contains the greatest variety of manufacturing-related capabilities at a single site. In addition to peel-apart and pocket film manufacturing, this site also contains consumer camera manufacturing, industrial camera manufacturing, and camera design. This is the only site that has both film and camera manufacturing, as even the US site no longer produces cameras. This is also the only site outside the US to have camera design capabilities.

Having film and camera manufacturing at the same site is especially valuable for an integral system design such as Polaroid's camera and film system. Such co-location facilitates quicker resolution of system quality issues which may be difficult to solve in isolation. The addition of design capabilities to the mix of film and camera production creates a dynamic environment that lends itself toward innovation.

The cameras produced at this site are specialty cameras that generally have lower volumes and are targeted at specific markets. The standard, high volume consumer cameras are produced in Asia to take advantage of lower labor costs. This site makes cameras that run for limited times, such as those featuring the Tasmanian Devil or Barbie, or marketed for Y2k.

4.1.4.2 Workforce – cost, skills, flexibility

The Scotland site is located in a region which has not participated in much of the economic growth seen in the nation's major cities. The labor force, however, is well trained and skilled, as one would expect from the breadth of functions existing at the site. Because of its economically depressed location, the site has been able to benefit from a skilled but low cost labor force. Additionally, the local government has provided numerous incentives for expanding the site and hiring more local employees.

The workforce at this site also stands out in its adoption of and proficiency in advanced manufacturing practices. This site began to incorporate the kaizen philosophy and process in 1996. Since that time, the employees have completed a number of activities. Examples include training and organizational changes that enabled greater flexibility of employees across the different manufacturing groups as product demand shifts. Similarly, other kaizen activities resulted in the elimination of considerable on-floor inventory that reduced costs and offered room for further expansion. Although all four film sites have implemented some form of kaizen or 6-sigma initiative, the Scotland site stands out in magnitude of their results.

4.1.4.3 Supply Chain

The Scotland site faces an identical supply chain situation as the Enschede site, with the additional constraint of longer transit time to the Enschede distribution center. The peel-apart film that is currently made at this site, however, is targeted at a different market than the integral film. Peel-apart film is primarily targeted at commercial users and thus has no real need for specialty packaging. This product difference decreases the obsolescence risk that would otherwise be associated with the greater distance from the DC.

The Scotland site has developed relations with some nearby suppliers that offer unique skills. This development can be attributed to the breadth of design and manufacturing capabilities at the site. The most prominent example of such a supplier relationship is a local supplier who has developed the technology to produce plastic parts for Polaroid in a wide variety of colors with short leadtimes. Polaroid employees worked to help develop this capability, which now enables quick prototyping of new camera designs.

4.2 Characteristic Matrix

While visiting the four film assembly locations, the key characteristics for an instant film site were identified. Attempts were made to use quantifiable metrics where possible. Each site was measured against these metrics, and the resulting data is included in Figure 7. The data for several factors is given in a disguised form to protect the interests of the company.

The table in Figure 7 displays the raw data collected through interviews and research. The data manipulation is done with an Excel macro created by the author specifically for this research. The Hi/Lo columns were created to enable a method to distinguish whether a given factor is preferably higher or lower in value. Data for factors with the Lo column marked are inverted by the macro while data for factors marked Hi are left unadjusted. This creates a temporary table in which all data is preferably high. The macro next manipulates the data by normalizing the data for each factor to an average of 2.5. Each of these data values is then multiplied by the weighting factor for that characteristic. The sum of these values is then normalized by the sum of the weighting factors. This is the final score that is used to compare the sites.

The final three rows in Figure 7 show the tabulated results for three different weighting schemes. Just as the list of critical factors varies from business to business, the relative weights of these factors also varies depending on the emphasis of the site. The three schemes shown in Figure 7 were created to represent different potential focuses for the assembly factories: low cost production (LC), time-to-market (TTM), and new product/process development (DV). These three different weighting schemes allow comparison from different perspectives and will be further developed in the Chapter 5.

The results of the characteristic matrix under the three weighting schemes are shown graphically in Figure 8. More appealing sites will trend toward the upper right corner or have bigger bubbles. It should be noted here that this analysis is done on a relative basis, and is useful for comparison only. As an example, it can be said that the Netherlands site appears less attractive for low cost or flexible manufacturing than the other sites. However, one can not say how the Netherlands site fares in an absolute sense. If the other three sites against which it is compared are ideal, it is expected that it will appear less attractive.

Portfolio of Manufacturing Capabilities										
		Good		Weightings			Plant Location			
Site Factor	Metric	Hi	Lo	LC	TTM	DV	United States	Mexico	Netherlands	Scotland
Cost of Labor	Average annual factory salary **		X	5	2.5	1	$2	$.5	$1.75	$1.5
Labor Productivity	# employees / assembly machine **		X	5	2.5	1	1.33	3	2	1.25
Labor Content	Productivity * wage **		X	5	2.5	1	$2.66	$1.50	$3.50	$1.87
Advanced manufacturing practices	10=part of org structure; 5=in implementation; 0=none or in concept	X		5	5	1	0	5	0	10
Workforce Flexibility	Temps as % of headcount **	X		2.5	5	1	95%	100%	20%	40%
Labor regulation	Cost to layoff employee **		X	2.5	5	1	1000	100	2000	500
Length of Supply Chain Pipeline	Raw materials inventory **		X	2.5	5	1	500	1000	3000	3200
Presence of Unique Suppliers	10=more than two; 5=one or two; 0=none	X		1	2.5	5	10	0	5	10
Proximity to Camera Manufacturing	10=onsite; 5=on continent; 0=none on continent	X		1	2.5	5	0	0	5	10
Proximity to Hardware Design	10=full capability onsite; 5=partial capability onsite; 0=not onsite	X		1	2.5	5	10	0	0	5
Language and culture match	% of English-speaking population	X		1	2.5	5	100	50	75	100
Workforce Education Level	National average years of education	X		1	2.5	5	15.9	11.0	15.8	16.5
Employee availability	Local unemployment rate	X		2.5	2.5	1	3%	3%	5%	12%
Exchange Rate Stability	Cost of currency hedging		X	2.5	2.5	1	1	5	3	2
Corporate Tax Rate	Corporate tax rate		X	2.5	2.5	1	37%	40%	35%	31%
Low Cost Factory Ratings							**2.37**	**3.03**	**1.40**	**3.20**
Flexible Factory Ratings							**2.70**	**2.82**	**1.36**	**3.12**
Development Factory Ratings							**3.06**	**1.42**	**1.86**	**3.66**

** Disguised Data

Figure 7. Site Characteristic Matrix

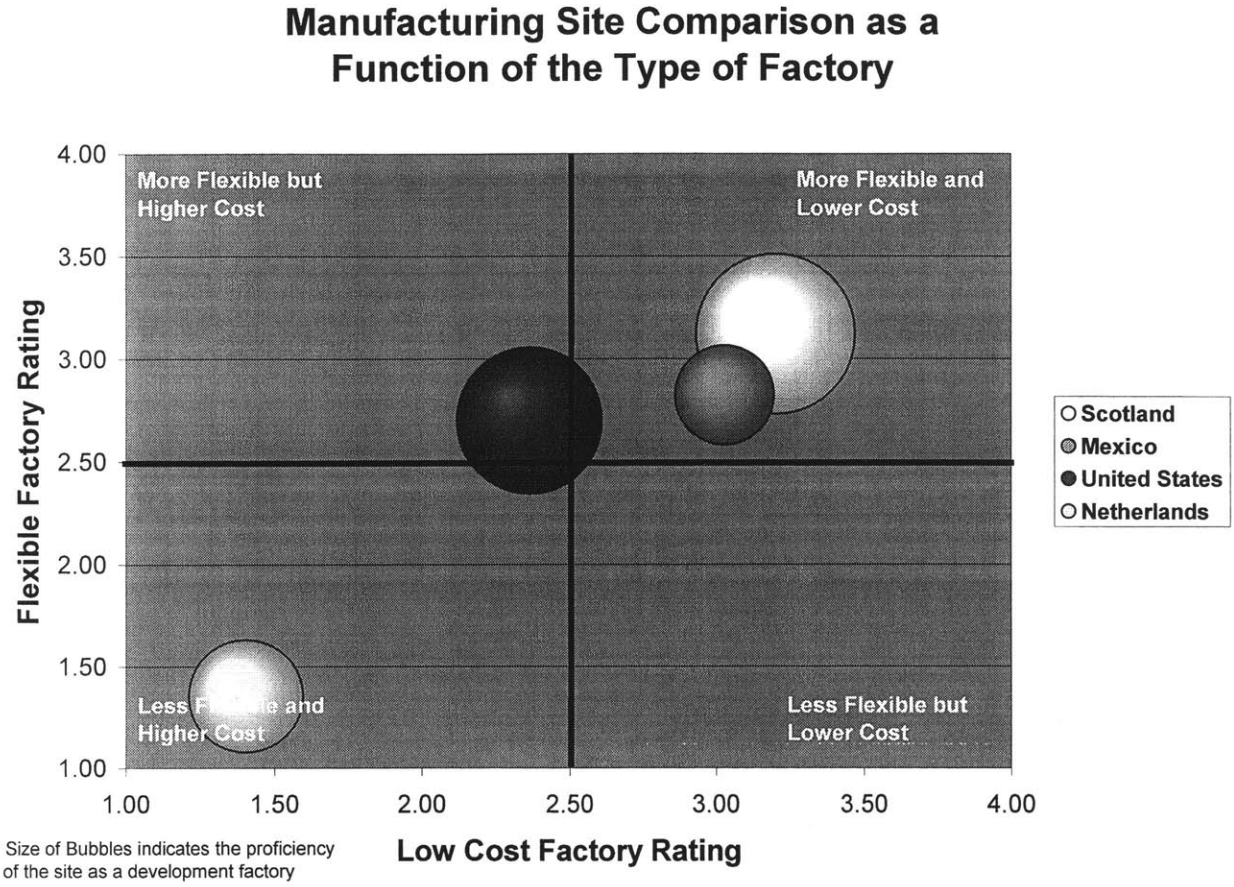

Figure 8. Characteristic Matrix Results

For low cost manufacturing, the characteristic matrix shows that Scotland and Mexico appear most attractive. This is primarily driven by the following factors: cost of labor, labor content, advanced manufacturing practices, and labor regulation. The first two factors are in strong agreement with the cost model covered in Chapter 3, which reinforces the notion that the two sites with lower labor rates offer significant potential cost savings. The characteristic matrix, however, also highlights differences in the workforce, such as the adoption of kaizen and labor flexibility.

For manufacturing which emphasizes flexibility or time-to-market, the US, Mexico, and Scotland sites all offer attractive propositions. The primary drivers of this are: workforce flexibility, labor regulation, length of the supply chain, and proximity to other functions such as camera manufacturing and design. A dissection of these results shows that the US offers proximity to the components and large US market, while Mexico offers the ability to

easily ramp the workforce to the upside or downside, and Scotland provides the capability to resolve system issues with both the camera and film expertise.

The US and Scotland offer the greatest potential as sites for new product development. Proximity to camera manufacturing and hardware design and the presence of unique suppliers are the largest sources of differentiation for this focus. In many ways, one would expect the US to clearly be the best site for development since that is the historic center of development and company expertise. In this analysis, it is slightly hindered by its lack of camera manufacturing, which was moved to Asia and Scotland in recent years. The matrix also makes no distinction in existing expertise. For example, it does not pick up the fact that most of Scotland's film expertise is in the peel-apart format while most innovation is focused on the integral format. In any case, though, a strong case can be made for the Scotland site's ability for incremental innovation or tailoring of existing products as well as the US.

4.3 Chapter Summary

Characteristic matrices allow the user to incorporate into the location decision factors which do not easily fit into a cost model. In the case for Polaroid, important factors such as proximity to design and camera manufacturing could be included through the matrix. Evaluations of the film assembly sites along criteria other than lowest cost, namely time-to-market and development capabilities, were also made possible with this tool. Clearly this method is useful for providing a broad picture of the capabilities of a site.

While the inclusion of more qualitative factors is an advantage of the characteristic matrix, one must use caution in evaluating these factors. Since they are by nature difficult to quantify, there may be significant play in assigning values. This can cause variance in results, or even permit skewing the data toward a desired outcome. For this reason, it is important to understand the causes behind the results and verify the values of key factors. Great care was taken in this analysis to use measurable factors that either directly or indirectly related to the costs of bringing products to market.

In any characteristic matrix, one must find the balance between the number of factors incorporated in the model and the robustness of the model. While some models used by consulting firms include hundreds of variables, this can decrease the granularity of the results. After the final results are tabulated it can be unclear what the major driving forces behind those results are. It is arguably even more important to determine the influential factors that are generating the differences in the attractiveness of sites than it is to determine which sites are most attractive. By focusing on a smaller number of variables, we were able to identify the leverage points which made sites more or less attractive for different plant objectives.

The results of the matrix are in general agreement with the cost model where comparisons can be made. Some new insights, however, include Scotland's appeal as a development and flexible manufacturing site, and the Enschede site's poor relative performance along cost and time-to-market criteria. This is mainly due to the combination of an inflexible labor force and moderate wages, while the longer supply chain also impacts its ability to manufacture rapidly changing products. While the detail of the cost model shows that the site is more cost competitive than the US site, both methods indicate the cost disadvantage versus both Mexico and Scotland.

5 Strategic Analysis

This chapter looks at some of the business issues that Polaroid is facing. A shift in the basis of competition for new products is having profound effects on the needs of the company's manufacturing capabilities. Understanding these new needs and how they interact with the needs of existing products will shed light on the issues surrounding plant locations.

5.1 Differences in Product Needs

For the better part of 20 years, Polaroid's integral and peel-apart instant film have generated significant growth for the corporation. Unfortunately, the growth in these products has slowed in recent years and the company now projects relatively flat volumes over the next three to five years. In order to stimulate new growth areas, Polaroid has responded by introducing products based on new film products such as pocket film and Joshua, which goes into the Joycam product. These new products have been very well received by the market. However, they also represent a whole new set of demands on the manufacturing organization.

Polaroid is in the midst of a radical shift in its product positioning. Whereas most prior designs placed more emphasis on functional performance, new designs such as the pocket camera, Barbie cam, and Taz camera shift that emphasis to fashionable consumer appeal. This new emphasis on fashion necessitates an increased frequency in product introduction cycles. Figure 9 shows the expected rate of innovation demanded from the different components of delivering an instant film product. New film formats will be less frequent than new cameras, but more frequent than the equipment needed to support those new formats. This same trend has been true of Polaroid's products in the past, but all three rates are being ratcheted up to meet the demands of the new market.

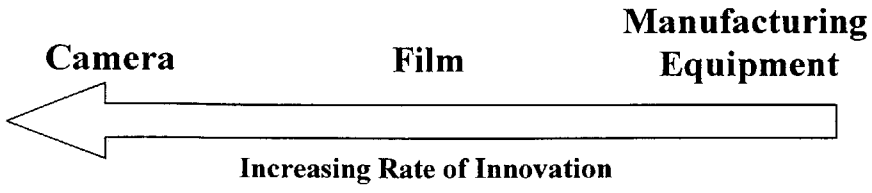

Figure 9. Polaroid System Clockspeed

Whereas Polaroid's traditional products competed on picture quality and cost, these new products are much more dependent upon time to market for commercial success. As product life cycles shrink to keep up with consumers' sense of fashion, market uncertainty of new products becomes a big concern. Polaroid must be able to quickly bring out new products not only to battle competitors, but also to adjust for shifts in consumer tastes. The flexibility of manufacturing processes to meet this demand will become a critical measure for sites.

5.2 Manufacturing Process and Equipment

Polaroid has traditionally used highly automated equipment for the production of instant film. Both integral and peel-apart film use large automated monolithic assembly machines to achieve high volume production. Given that the volumes of the integral and peel-apart formats have been so great and required little change in the manufacturing process, the use of highly automated equipment has been extremely beneficial. This equipment is ideal for achieving high volumes at low cost.

However, improvements to this monolithic equipment are extremely difficult due to its lack of modularity and accessibility. As a result, most of the skilled labor is not directed toward improving the equipment but rather simply troubleshooting production issues as they arise. Although considerable experience is necessary to troubleshoot the machinery, a significant amount of the labor consists of simply loading components and unloading finished goods. Overall, these factors create a scenario that reduces the synergy normally seen between automation and highly skilled labor. The degree to which this type of monolithic equipment will be used for future products will be an important factor in determining the need for skilled labor and making location decisions.

New products, however, will experience much more rapid innovation. As an enabler of this innovation, Polaroid must create a more flexible process. This can be done by decreasing the level of automation or by increasing the flexibility of equipment. If the manual process is chosen, low cost labor will be a key determinant in site selection. If flexible equipment is selected instead, an educated workforce that can make improvements to the process and manage the flexibility will be more valuable.

As an example, Polaroid has taken both approaches to flexibility with its new pocket film format. The manual process, which is implemented in Mexico only, has enabled a steeper ramp by eliminating lead time issues with new equipment. All three sites have implemented the semi-automated process, which is more flexible than the process for integral and peel-apart film. This process breaks the assembly into more discrete parts, which can be improved and changed over more easily than in a monolithic design.

Equipment design and improvement is becoming a more critical capability with the rapid innovation rate of new products. When the integral and peel-apart formats were in development, Polaroid employed an internal equipment design group. This group was responsible for the initial equipment designs as well as continuous improvement in equipment performance. The equipment for these processes was highly specialized, so there was considerable value in the internal design capability. The long intervals between new products made it difficult to justify retaining this capability, however. As a result, Polaroid currently has only a small team of equipment designers.

For pocket film, Polaroid contracted with 3rd party vendors to jointly design the equipment that the vendor then manufactured. The increased importance of equipment design requires that Polaroid either regain this strong capability or manage this relationship extremely well. These vendors are located in the US, as is the small remaining internal equipment design team. The US site, then, is ideally positioned through both physical proximity and technical expertise to serve as the development site for new equipment and processes.

5.3 Effect of Plant Focus

Although there is little hard evidence, most experts agree that factories need to have a focus. The most common strategies are to align factories by products, geographic markets, or life cycle stages. Product strategies are generally appropriate for products with large economies of scale or high complexity. Market strategies can respond to local differentiation in product needs and minimize distribution costs and duties. Life cycle strategies separate development capabilities from manufacturing capabilities to sequentially attain quick time-to-market and low cost production.

Polaroid's current plant focus strategy is based on products. Scotland and Mexico make the peel-apart film while the US and Netherlands sites manufacture integral film. There is also some degree of market focus, as the US and Mexico sites supply the Americas while the Scotland and Netherlands sites primarily supply Europe, Asia, and Africa. However, this sourcing strategy is flexible and adjusts to take advantage of changes in exchange rates and product costs. For example, Polaroid periodically shifts some integral film production to the Netherlands plant when it can supply the American market at a lower cost, or vice versa.

The addition of new products such as pocket film brings back into question the most appropriate plant focus for Polaroid. Rather than establishing new sites, pocket film equipment has already been installed in three of the four film factories. This overlap of old and new products within the same sites already marks a departure from the product focus previously employed. As mentioned earlier, new products demand quick time-to-market whereas older products are competing more on cost. New products may well be best served by a life cycle strategy while older formats utilize the existing product strategy.

5.4 Summary of Strategic Factors Affecting Plant Location

There is no right answer for how much flexibility to design into new processes, whether to achieve it through manual labor or flexible automation, or which plant strategy to implement. New products will clearly have shorter life cycles and need more flexibility, but success is independent of the method. The critical factor is that each of these choices be made in concert to create a cohesive strategy. The implications of this strategy upon the factory network will then be clear.

With their emphasis on cost, integral and peel-apart film lend themselves towards production at sites with the lowest cost, even at the expense of lead time or flexibility. The manufacturing processes and equipment are well developed. Special skills are required to troubleshoot the equipment in the dark, but these skills can be learned through experience and leveraged across a number of machines. Long lead times are not as important either, as demand is mature and proliferations are few. There does not appear to be such a strong need for the plants to focus on integral or peel-apart formats separately. Instead, these

products both require low cost manufacturing as they are in the later stages of their life cycle.

New formats such as pocket film, however, place greater value on a manufacturing organization which can quickly bring new products to market and ramp volumes up or down at the minimum cost. Developing new products requires extensive product and equipment expertise. Whether the design team for new process equipment is internal to the company or external, there is a strong need for this group to be closely integrated into the product design process. Since the US continues to be the main development site, that assembly factory will play a critical role in bringing these new products to market.

Mexico offers another set of characteristics that are appealing for the development phase of new products. The ramp for pocket film is indicative of these possibilities. At the onset, the market for pocket film was highly uncertain. Polaroid planned to launch the product in Japan first, to gauge the product's appeal to an advanced customer base. A manual assembly process was designed in the US and implemented in Mexico. Mexico offered the opportunity to minimize the investment and provide a cost-effective solution while the new market was tested. In the case of an unsuccessful launch, Polaroid could also easily downsize the workforce at little cost. When demand came in even greater than anticipated, this site was able to quickly increase site capacity through hiring and training new workers for the manual assembly process.

Both the US and Mexico also offer the advantage of being close to the large American market. Although Japan was the test market for pocket film, the US market has been the initial market for most products and proliferations. Such close proximity minimizes shipping delays and obsolescence costs. If the development site is not close to the early markets, airfreight of finished goods will need to be seriously considered.

6 Conclusions

6.1 Synthesis of Results

Polaroid is facing a divergence in product needs that is challenging its traditional methodology for allocating production across the four film assembly sites. The high volume mature products are continuing to live out their long life cycles while at this point competing mostly on cost. New products, however, will have much shorter life cycles, requiring rapid innovation and flexible manufacturing. With these two sets of needs in mind, we can use the results of the cost and characteristics models to design an appropriate location strategy.

6.1.1 Approach for Mature Products

The cost model results show that Mexico and Scotland currently offer the lowest cost sourcing options. The Netherlands site is the next best option, and the US offers the least competitive cost structure. By analyzing the sensitivity of the results to exchange rate fluctuations, however, we determined that any of the four sites could potentially offer the lowest cost in the future. We cannot predict future fluctuations in currency value, but the differences in cost are within the range of past variance. Keeping in mind that shipping costs are negligible for these products, this parity in cost suggests that a system with built-in short term flexibility may offer the best solution for mature products.

The majority of instant film is currently produced at the US and Netherlands sites. Although Scotland produces the majority of peel-apart film, the volume of that format is much smaller than the integral format. A strategy of balanced capacity among the sites, however, would offer the ability to shift production to the lowest cost sites. Excess capacity currently exists in the system, and could be moved to the Mexico and Scotland sites to balance capacity and take advantage of the lowest cost. It is not cost-effective to repeatedly move assembly machines, but a one-time move could provide additional capacity at the lowest cost sites and offer more protection against future currency shifts.

6.1.2 Approach for New Products

As discussed in Chapter 5, Polaroid's new products require a plant strategy based on the product life cycle. Sites that focus on development will be able to bring new products and processes to market quickly and frequently. In concert, sites that focus on the volume ramp provide great upside and downside flexibility to adjust to market demand. Finally, sites that focus on low cost manufacturing can meet the demands of products in later stages. This strategy can overlap with the integral and peel-apart strategy if these are considered to be products in the later life cycle stage.

The characteristic matrix identified the US and Scotland as the sites having the best qualifications for development projects. After delving into the observations behind these results, we established that the US was best positioned for large development projects. The Scotland site has the capability for smaller projects, such as proliferations, as well as projects that integrate camera and film manufacturing expertise. From this analysis, the US is identified as the primary site for activities in the development phase of new products.

With its flexible workforce and proximity to the US site, the Mexico site is the ideal candidate for the ramping phase of new products' life cycle. The financial risk associated with products in the ramping phase is high. Market uncertainty is great, and the company can lose much from either underestimating or overestimating demand. Mexico's low labor rate is ideal for implementing a manual or semi-automated process early in a product's life cycle. After receiving market feedback, production can be scaled up or down rapidly while design changes are made or other sites come online with their capacity.

In summary, the US should serve as the development site for new products. Scotland can contribute to the development activities through small design changes and through integrated system designs. New products can then be manufactured initially in Mexico to provide flexibility. In the later stages of product life cycles, capacity is split among the sites to provide protection against exchange rate fluctuations. During this phase, demand is shifted to take advantage of excess capacity at the lowest cost sites.

In this analysis, three of the four sites were identified with unique capabilities in a network of plants with a life cycle focus. The Enschede site, however, is not exceptionally

positioned along cost, manufacturing flexibility, or development capability. While this site offers a fourth option for taking advantage of exchange rate variance, it is not clear that this is enough incentive to continue using the site in its current capacity. An evaluation of this site should commence to identify the value this site can add to the factory network. Changes need to be made to cultivate new value-added capabilities, or the plant should be shut down.

6.2 Methodology Critique

It is important to note that most of this analysis has ignored pre-existing assets at the sites. For example, the cost model assumed that the existing capacity was able to produce whatever type of film was desired. Similarly, the characteristic matrix did not specify in what type of film a site has expertise. Ignoring existing assets allows decisions to be independent of previous decisions, which allows us to explore the ideal case. However, the solutions using this approach do not take into account the costs of converting from the existing situation to the ideal solution.

Although new investment decisions can follow the solution to our analysis, adjustments to existing assets need to be evaluated on a financial basis. For example, the transition costs for closing the Enschede site or moving more integral film capacity to Mexico and Scotland may make these actions economically undesirable. Thus this analysis is useful for future decisions, but needs to be rigorously evaluated for changing decisions that have been made in the past.

6.3 Lessons Learned

The following list summarizes personal insights that I gained during this work over the course of six months at Polaroid:

- **In modeling, simpler is often better.** Many cost models attempt to account for every potential source of variance. The complexity of these models, however, requires increasing amounts of work, and often cloud the logic behind results.

- **Multiple perspectives enrich the picture.** The approach of this research initially focused on a single method for evaluating site locations. By integrating three different perspectives, however, we created a more accurate description of the needs facing the organization and the value of potential solutions.

- **Decisions with long term implications must be ready for an uncertain future.** Because of the high fixed costs, opening and closing facilities must take into account more than the present situation. Especially in an international context, today's best solution will likely perform poorly in a changing environment. The future cannot be predicted, but these decisions must be evaluated under alternate scenarios.

- **Growth ameliorates weaknesses in the factory network.** Strong growth allows factories to run at near-full capacity, amortizing fixed costs over large volumes. When growth slows or even stops, the cost disadvantages of sites are magnified. Flexible manufacturing offers some protection from this effect, but must be designed into the process early in a product's life.

7 Endnotes

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