Automotive Painting:
An Economic and Strategic Analysis

by
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Abstract

The automotive paint industry is in a state of pronounced transition, primarily because of:

- Environmental considerations due to EPA regulations.
- Changing materials composition of automotive exteriors due to CAFE regulations.
- Increased cost and quality consciousness of automotive manufacturers due to intense competition in the automotive industry.

To respond to automotive manufacturers and the changing conditions in the industry, while maintaining competitiveness, it is crucial for automotive paint suppliers to understand the economics of automotive painting. A process based cost estimation model was developed for the automotive painting process and employed to examine the economics of automotive painting. It was also used to evaluate the cost implications of process changes and alternative technologies. The results of the model indicate that materials and capital are the most substantial contributors to automotive painting costs.

The significant contribution of materials to painting costs will cause escalating pressures on paint suppliers to reduce margins. In addition to improving paint cost and quality, paint suppliers can respond by providing alternatives that reduce the overall cost per car painted. The high capital costs imply that subsequent to the installation of a painting line, alterations will not be made casually.

Environmental pressures, along with increasingly stringent quality requirements, are causing a transition from solvent based to water borne paint systems. Presently, aqueous systems are more expensive, and not necessarily environmentally friendlier, than the solvent based systems that they replace. However, their superior quality, as well as a promise of lower costs and improved environmental performance in the future, is causing aqueous systems to replace solvent based systems.

The changing materials mix in automotive bodies will not significantly impact the economics of painting in the short term. The capital investment required for automotive painting lines is too prohibitive to readily accommodate changes. However, for research and development purposes, paint manufacturers need to consider the disparate painting requirements of alternative materials, since their usage is on the rise.

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Chapter I
The Automotive Paint Industry

Painting a car is one of the most expensive operations in automotive manufacturing. The paint shop typically comprises 30-50% of an assembly plant's cost. It is where the most expensive mistakes often occur; where some of the worst accidents happen, and where the heaviest Environmental Protection Agency (EPA) fines are levied[1]. Building a new paint shop can cost $150 million to $450 million or more, and strict new environmental regulations are increasing costs consistently. With prices ranging from $50-$100 per gallon, even when purchased in bulk, the paint itself is also a precious commodity.

The paint job is the first thing a shopper notices on a car, and the paint color and quality can make or break a sale. "Appearance is very important in judging the quality of a car," says Imaki, a senior research official at Mazda, "and color is one of the most important considerations in determining appearance."[2] The latter makes constant improvements in quality and color crucial. As automotive makers strive to make better looking, longer-lasting finishes, the costs continue to burgeon. Automotive makers to-day cannot follow Henry Ford, who once told car buyers they could have any color as long as it was black.

The U.S. market for automotive paints and coatings was $1.7-billion in 1991, with PPG, BASF and DuPont as the major players (see Exhibit 1-1). The automotive market for paints and coatings is complex due to the four coatings applied to auto bodies: an electrocoated primer, followed by a primer surfacer, basecoat and topcoat/clearcoat. The industry leaders, while supplying all four coatings, tend to have specializations in specific coatings.

PPG Industries is a leading supplier of products for manufacturing, building, processing and numerous other global industries. Established in 1883, the Pittsburgh based company makes flat glass and fabricated glass products, continuous strand fiberglass, decorative and protective coatings, and industry and specialty chemicals[3]. It is the world's largest supplier of automobile paints. PPG's increasing dominance in the industry stems from its development of advanced systems for electro-coating car bodies. The process developed by the company provides a coating underneath the primer and topcoats that prevents corrosion. It is the principal element in automotive anti-corrosion guarantees.[4] In 1976, PPG developed the first commercially viable system in which the resin and pigment could be charged positively, with the car body wired as a cathode. This resulted in even deposition and better adhesion of the paint. The result has been that PPG now has 63 per cent of all electro-coating tanks in the world, while another 30 per cent use PPG technology under license. The technology has made PPG the leader for all automotive coatings applied in the factory, with twenty one per cent of the world market.

Exhibit 1-1: Top Suppliers of US Automotive Topcoats, 1991
(in millions of dollars)

Supplier	Solvent	Water	Primer	Total
PPG Industries	$260	$31	$270	$561
BASF	$255	$65	$190	$510
DuPont	$265	$3	$125	$393
Total	**$780**	**$99**	**$585**	**$1,464**

Source: Chemical Week, October 14, 1992

In addition to developing new technology in-house, acquisitions and joint ventures form part of PPG's strategy for growth in this industry. PPG reached an agreement to purchase ICI Canada's OEM automotive paint business in 1991. The acquisition effectively removed ICI from the North American original equipment market automotive coatings business, which PPG dominates with a 55%-60% market share. This move also fit well with PPG's desire to acquire a high quality water based color system. ICI's proprietary water based technology, Aquabase, has been the key to its success with GM, and with GM moving to shrink its supplier base, PPG's acquisition could not have been better timed. In 1991, PPG also strengthened its presence in the European automotive paints and coatings market by forming a joint venture with Sweden's leading industrial paint manufacturer, Wilhelm Becker (Stockholm).

DuPont is a diversified company whose key segments span chemicals and fibers to polymers, petroleum operations and diversified units such as agricultural products, imaging systems and medical accessories. DuPont currently is developing paints that it hopes will look new even after 10 years of hard exposure to the elements, and that could carry 10-year warranties. A DuPont insider hints the chemical giant is toying with the idea of using Teflon as a means of getting such durability.

DuPont has also been acquiring companies and forming joint ventures in this industry. The O'Brien Corp., a paint manufacturer in California's Bay Area, sold its automotive paint division to the DuPont Co. in 1991. DuPont's move in acquiring small, 100 person operations is aimed at limiting competition to the three major players: PPG, BASF and DuPont. DuPont Automotive Products created a joint venture with Kansai Paint Co. Ltd., of Osaka, Japan, with a view to capturing $40 million annually in sales of automotive paint coatings.[5] The two companies have targeted Japanese and Korean automotive makers and their component suppliers in North America, as well as North American joint ventures between US and Asian automotive manufacturers.

BASF Corp. is the US. subsidiary of West German chemicals giant BASF AG. Not to be outdone by its competitors PPG and DuPont, BASF has acquired the family-owned Mexican paint manufacturer Aurolin, which had group sales of $22 million in 1988. The Mexican factory has a modern plant which could be expanded by BASF. BASF's acquisition could turn out to be significant with the enactment of the North American Free Trade Agreement. BASF is also investing heavily in research into water borne and powder coating systems, with a long term view that these would be the systems of choice in the years ahead.

The US paint manufacturers primarily supply the three American automotive companies, some foreign transplants, and second party suppliers. Although all three major paint producers have a world presence, the US market only has a few buyers, resulting in significant buyer power. This is heightened by recent trends in the US automotive industry to move towards dictating automotive supplier margins and shrinking the supplier base; GM is a prime example.

It is unlikely that there will new entrants in this industry due to high entry costs, coupled with the fact that the industry is concentrated with players who have substantial staying power. The incumbents have signaled their intentions of retaining and gaining market share via their aggressive acquisitions. The relatively small number of buyers also pose entry barriers as a new entrant would have to break into the tight network that the buyers already have with the existing suppliers. The automotive companies are not inclined to change suppliers with ease because painting is such an expensive process and is critical to the performance and perception of cars. Lastly, there are technological barriers to entry; paints are very complex systems and their manufacture involves both science and art. It would be difficult for a new entrant to manufacture automotive paints, given the stringent quality requirements.

Change in the Automotive Paint Industry

While there is no threat of new competition in traditional automotive paints, there are several imminent threats to conventional automotive painting technology primarily due to external influences. The automotive paint market is in a marked state of change. "Auto finishing has changed more in the past 10 years than it had in the previous 60," says Ross W. Fasick, group vice president at DuPont Automotive Products[1]. Substitutes to the conventional solvent based automotive paint systems are being aggressively developed and pursued by automotive companies, automotive paint suppliers and other chemical companies. Change in the automotive paint industry is driven by three major factors: environmental regulation, the changing materials mix in automotive bodies, and the increased cost and quality consciousness of automotive manufacturers[6].

Environmental Regulation

One of the biggest drivers of change in the US and Europe is tougher environmental legislation aimed at reducing volatile organic compound (VOC) emissions from paint shops. The Clean Air Act Amendments of 1990, signed by President Bush on Nov. 15, 1990, will have a major impact on virtually all industrial operations[7]. While the impact of the Clean Air Act on automobiles, or "mobile sources" of pollution is well known, the implications for factories, or "stationary sources" of pollution, are lesser known. Nevertheless, there are significant ramifications for manufacturing processes that have undesirable by-products. Automaking facilities will be hard hit because they are high energy users, and their assembly plant painting operations use several chemicals that are on the Environmental Protection Agency's hit list [8].

A survey of manufacturing engineers by Ward's Auto World shows OEM and supplier manufacturing operations already have been significantly affected by the act[9] because the costs of staying clean and of being caught "dirty" are increasing. The Ward's survey finds that the new act will force substantial changes in manufacturing operations over the next several years. Interestingly, although most automotive industry officials say painting operations will be most affected by environmental regulation, survey respondents think waste disposal will be hit hardest.

The newer automotive plants in the U.S., Honda of America's East Liberty, Ohio Plant, Saturn Corporation's Spring Hill, Tennessee Facility, and Chrysler Corporation's new Jefferson Avenue Plant in Detroit have made the environment a top priority, even though all the measures they have undertaken have not yet been mandated by government or state agencies. In general, companies are opting to spend extensively up front on costly waste recovery and pollution control devices rather than risk even more expensive EPA fines down the road.

An innovative technology to deal with paint waste has been pioneered by Haden Environmental Corporation of Troy Michigan. Its "DryPure" process dries the paint sludge, which is basically paint that is not deposited on vehicle bodies and is a major toxic byproduct of painting vehicles. The paint sludge's volume and weight is reduced by approximately 90%. Chrysler uses this $2 million system for recycling paint sludge[9]. The paint overspray is converted to a non-hazardous powder which is used as a filler for pavement cracks by a local chemical company, and as an underbody paint on Dodge trucks. This is definitively a creative way to ease the burden on landfills and find a useful home for what was once an unwanted by-product.

Companies have had to pay millions of dollars to clean up waste sites they used years ago, and they may have to spend millions more in the future to clean up what they are legally disposing of today. Hence, they are becoming increasingly conservative in their treatment of waste. For example, even though paint sludge can be classified as hazardous and non-hazardous, several plants treat all paint sludge as hazardous. As a result, even though they have to pay higher disposal fees for the hazardous sludge now, their liability in the future will be limited.

While automotive companies are spending extensively to treat waste and VOCs in an appropriate fashion, this expenditure does not really add value to their end-product, the car. Therefore, not surprisingly, there is a focus on modifying painting technology with a goal of increased environmental compliance. The aim is to alter the painting process such that there is a reduction in waste generation. PPG Industries Inc., BASF Corp., DuPont Co., and other major paint and chemical suppliers are continuing to respond with technologies that lower or eliminate solvents and volatile organic compounds. However, industry sources say it is getting tougher because in the past decade they have cut paint-plant emissions by 70%, and they are running out of room for improvement. Consequently, there is a drive towards research in water borne and powder coatings.

Suppliers are rushing ahead with new technologies such as water-based paints and powder coatings that do not use solvents. Other innovative solutions being offered include pre-painted steels, mold-in color for plastics, and paint films. Himont Inc.'s Advanced Materials Div. in Lansing, Mich., has successfully offered plastic bumper covers with color that is molded in rather than painted. Because painting is so expensive, GM estimates the colored bumpers save $ 40-$70 per vehicle[9].

In brief, the Clean Air Act Amendments' stringent stance on solvent emissions and chemical waste is increasing the attractiveness of alternative paint technologies which are environmentally friendlier. Environmental concerns are increasing the pace of change, and in response plants are shifting to water-borne paints or contemplating powder painting, even though these technologies might be more expensive.

The Changing Materials Mix in the Automotive Industry

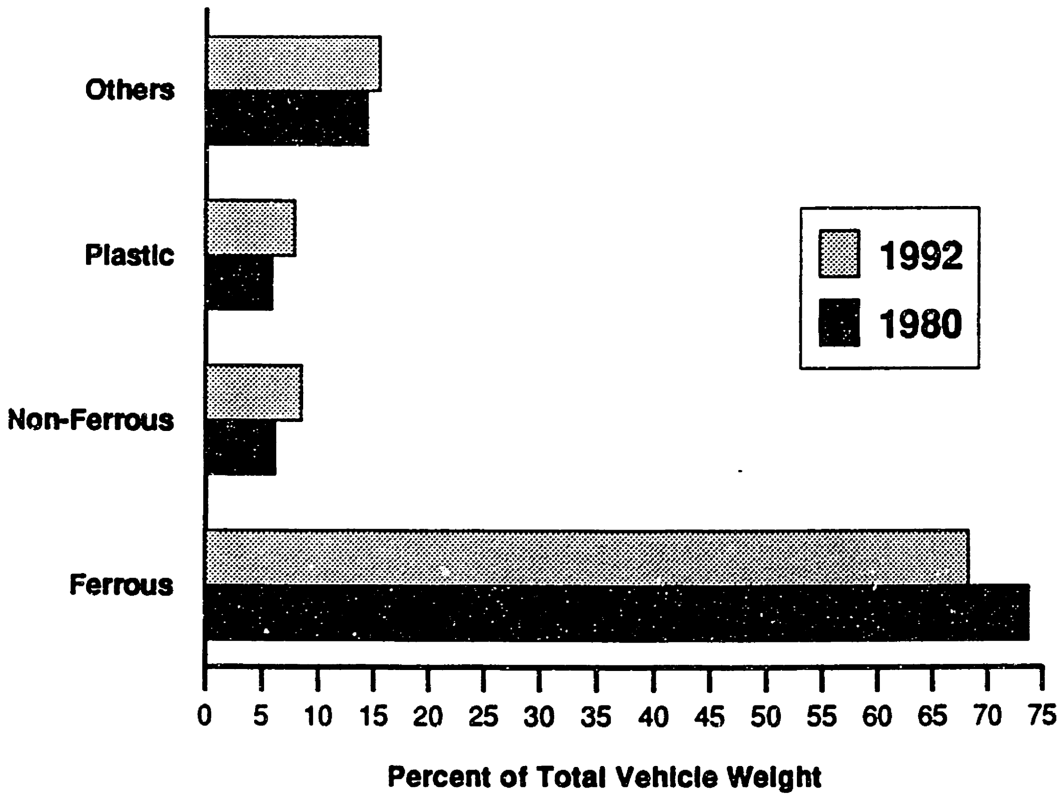
In response to regulatory pressures, automotive makers are developing lighter weight vehicles that are more fuel efficient. CAFE (Corporate Average Fuel Economy) regulation has caused weight reduction to become a major target for auto makers and has resulted in an interesting array of alternative automotive body materials[10]. There has been a significant increase in the use of plastics and other lighter weight materials such as aluminum in car bodies as displayed in exhibit 1-2. Various forecasts indicate that plastic parts will continue to account for an increasingly large percentage of automotive components[11].

This move away from the use of traditional steel for car bodies has tremendous implications for the automotive paint manufacturers. For example, the increasing use of plastics in car bodies creates the need for paints that cure at lower temperatures, because certain plastics cannot withstand heat in the manner that steel can. Aluminum presents different issues, such as problems with the electrodeposition process if it comprises more than 10% of the car body. The implications of materials substitution in automotive body panels for automotive painting are discussed in detail in chapter six.

Increased Quality and Cost Consciousness of Automotive Manufacturers

Increasing customer acceptance standards are raising the emphasis on quality in paint finishing. While the automotive industry is seeking ways to reduce VOC levels and incorporate alternative body materials, it is not at the expense of poor quality. Research

Exhibit 1-2: Materials usage in the automotive industry
Source: Ward's Auto Book



has never been more active as far as improvements in coating performance and quality are concerned. The focus on improving quality is from the perspective of both the paint and the application process. Chrysler's Jeep Grand Cherokee plant improved the quality of vertical surfaces by using an "enhanced-flow" basecoat supplied by BASF and driving out basecoat solvents before the application of the clearcoat[12]. These modifications helped alleviate the problem of low paint quality on vertical surfaces. In several instances, paint manufacturers are working in conjunction with the automotive companies and equipment suppliers to identify means of achieving substantial improvements.

Given the competitive environment, auto makers are constantly in search of ways to reduce cost without sacrificing quality. Painting is one of the most expensive steps in the manufacture of cars[13]. Consequently automotive companies are seriously interested in technologies that reduce painting costs. Reductions in painting costs can be attained in a number of different ways. They could be attained via reductions in the costs of paint. Additionally, they could also result from paints that are cheaper to use such as paints that cure at lower temperatures, and hence yield energy savings. Another example would be a paint that has lower VOCs per gallon, which is cheaper to use because it reduces the costs of waste treatment. Process innovations that impact costs favorably include increased transfer efficiency or reduced painting defects per car.

The increased cost and quality consciousness of automotive makers is changing the relationship that paint manufacturers have had with automotive manufacturers. To quote a senior executive at PPG, "In the past we could focus mainly on mixing paint. But now we need to understand the entire automotive painting system because of pressure from automotive manufacturers."[14] Automotive makers need to reduce costs while improving quality and are turning to paint manufacturers to be partners in this process. Traditionally, the relationship between paint manufacturers and automotive makers did not extend much beyond the sale and purchase of paint. However, this pattern is rapidly changing and paint manufacturers are getting increasingly involved with automotive makers. In fact, in one GM plant, PPG runs the paint line and, instead of remunerating PPG on the basis of paint consumption, GM compensates PPG on the basis of cars painted with acceptable quality.

Paint manufacturers need to understand the economics of painting a car in order to better serve their customers and remain competitive. Currently, automotive paint manufacturers are not in a position to easily assess the economics of painting. As they have mainly been involved with supplying paint, they have not experienced a need to understand the economics of the actual painting process. In situations where they are beginning to get involved in the painting process, they are typically relying on cost estimation techniques which have historically been set up for traditional accounting purposes. These techniques are not useful in assessing the cost implications of process changes or the contribution of various steps to the total painting cost. They certainly cannot be used for determining or forecasting the impact of strategic variables or changes in technology.

Grasping the economics of automotive painting is of value in several ways. It gives paint manufacturers options to respond when automotive makers are trying to squeeze their margins. By understanding the costs involved in painting, paint manufacturers can respond by suggestions on how to achieve cost reduction by means other than reductions in material costs. Understanding the economics could also help paint manufacturers in research and development decisions, and the marketing of new paints. For example, it could be used to assess the savings from the usage of a new paint that cures at lower temperatures or has reduced levels of VOCs. Depending on the economics of painting, paint manufacturers could assess whether an investment in developing this paint would be beneficial. If this paint is more expensive than the paint it is replacing, the model could be used as a tool to communicate and demonstrate to customers, the savings that would result from utilizing the new paint.

The automotive paint industry is in such a state of flux that it would be valuable to have a methodology to evaluate alternative technologies on an economic basis. External factors such as environmental regulations and the changing materials mix in automotive bodies are propelling change in both automotive painting technology and the industry. Several new technologies such as aqueous based paint systems and powder painting are becoming popular. However, even though environmental compliance and paint performance is important, cost is frequently key to whether a new technology is adopted.

This thesis renders an economic analysis of the automotive painting process via the construction and use of a process based cost estimation model. The thesis also examines other strategic factors that are key to being competitive in this industry. Due to the complexity of the painting process, estimating the cost of painting a car is not a trivial task. The modeling approach breaks the painting process into distinct unit operations and separates the various cost elements for each unit operation. Data used to construct the model is obtained through plant visits and numerous phone interviews with industry experts. Thus the model is a fairly accurate representation of the automotive painting process and can be used for several purposes. It can be used to obtain the components of the costs involved in painting a car. Sensitivity analysis can aid in understanding the prime movers of painting costs and provide leads regarding approaches to cost reduction. Further, the model can be employed to evaluate the economic implications of alternative painting technologies.

Chapter III

Process Based Cost Estimation of Automotive Painting

Painting a car is a complex multi-step operation. Needless to say, estimating the cost of painting a car is not an elementary task. The issue of cost, however, as discussed earlier, remains central to the evaluation of alternatives and the decision making process. A useful tool for estimating the cost of complex manufacturing operations is a process based cost model. Process based cost estimation takes a bottoms up approach to estimating costs[15]. It breaks the manufacturing process into small, manageable steps or unit operations and separates the different cost elements for each unit operation. Thus the estimation, while employing clearly defined and verifiable economic and accounting principles, is based on engineering principles and the physics of the manufacturing process. This chapter briefly describes the automotive painting process and the modeling methodology that was used to construct a process based cost model of automotive painting.

3.1 Automotive Painting Technology

Automotive coatings provide corrosion protection and improve the aesthetic appeal of a car. The demands and performance required of automotive coatings are considerable. They should provide adequate protection to the car body and prevent corrosion of any form during normal usage, including attacks due to road salt, gasoline, harsh chemicals, bird droppings, etc. In addition, from a manufacturing or process perspective they should readily lend themselves to mass production methods and hence should be robust and easy to apply.

To meet these stringent performance requirements, the automotive paint job consists of multiple layers and the process involves several steps. For the purpose of this analysis, as displayed in exhibit 3-1, the painting process is treated as five major groups of unit operations: pretreatment, electrocoat, sealer, primer-surfacer and topcoat. This approach is appropriate for cost estimation as it breaks down the painting process into individual unit operations. It is pertinent for strategic analysis because competition and change generally occur on the basis of these groups. Consequently, to evaluate changes in the industry or the technology, it is beneficial to approach the painting process in these smaller segments.

Exhibit 3-1: The Automotive Painting Process

I. Pre-Treatment	1. Clean & Rinse

II. Electro-Coat	2. Application 3. Bake 4. Inspection & Rework

III. Sealer	5. Application

IV. Primer-Surfacer	6. Application 7. Bake 8. Inspection & Rework

V. Topcoat	9. Basecoat Application 10. Basecoat Dry 11. Clearcoat Application 12. Clearcoat Bake 13. Inspection & Rework

Pretreatment

Pretreatment is the first unit operation in the painting process. It is only a fraction of the cost of the entire painting process, but it is key towards paint performance. For example, a car costing $20,000 may have only $2 maximum of pretreatment[16], yet the pretreatment is crucial in regards to the performance of the car body. It has three purposes:

- to clean the car and remove oils and any other temporary coatings
- to improve paint adhesion by providing an inert layer of metal phosphate
- to provide resistance to the spread of corrosion

There are several steps in the pretreatment process; the exact number typically varies from plant to plant and ranges between five and seven. These steps include rust removal, alkali degrease, water rinse, conditioning rinse, metal phosphating, acid wash and demineralized water rinse. In the older plants, almost all of these steps use spray systems.

while in newer plants dip systems are becoming popular. The trade off between dip versus spray systems is that of capital versus material costs. Additionally, the quality in dip systems is arguably better. The phosphating step is key in pretreatment as it modifies the metal substrate to produce an integral phosphate layer that aids in adhesion and corrosion prevention.

Electrocoat (E-Coat)

Electrocoating is the electrolytic deposition of a water borne resin, its main purpose being corrosion prevention. Since the late 1970s, cathodic electropaints have been used rather than anodic electropaints because they provide superior protection and are more stable. Cathodic electroprimers had always been acknowledged to be theoretically desirable because of their anticipated freedom from substrate disruption and the fact that cationic resins, being alkaline in nature, would be inherent corrosion inhibitors free from saponification[17]. However, the complexity of the required resin systems precluded the early introduction of cathodic systems. In the early 1970s, successive outbreaks of serious motor vehicle corrosion combined with legislation for minimum corrosion standards promoted the development of cathodic electrocoats. Thereafter, cathodic technology rapidly replaced anodic products in North America as results from test track evaluations confirmed the superior protection of cathodic systems. A significant advantage of a cathodic system is its excellent 'throwing power,' which is basically the ability of the e-coat to access the remote recesses and box sections of a car.

Installations for electrocoating are capital intensive, consisting of equipment for e-coat circulation, refrigeration, filtration, and the provision of a direct current power supply, in addition to the e-coat tank itself. During electrocoating, the car is immersed in the e-coat tank for two to three minutes during which a direct current is passed between the car (cathode) and an anode. As a result, an insoluble coating is deposited on the car. The coating is compact, almost dry, has very high solids and strongly adheres to the pretreated metallic body. After baking at approximately 350*F, the resin cures to form a tough durable film. The car is manually inspected for any defects and reworked if required, either before or after the baking step.

The amount of e-coat deposited depends on the quantity of electricity passed. As the film is deposited the electrical resistance increases and deposition slows. This ensures progressive deposition into remote areas and box sections, as the electrical current is forced to pass through these areas once the external surface has been coated.

It is expected that electrocoating will continue as the best anti corrosion primer technology until at least the end of the century[18], primarily because there are no new competitive technologies in sight. Current trends in electrocoats include:

- developing lead-free formulations
- lowering baking temperatures from 350 to 250*F
- reducing the level of volatile organic compounds (VOCs) from about 1.2 lb./gal to 0.6 lb./gal, with the ultimate goal of eliminating them.

Primer Surfacers

The principal function of primer surfacers is to 'fill' the surface to hide any minor imperfections and marks that might have arisen during the pressing and assembly operations. A good primer-surfacer will provide an unblemished even surface that will maximize the appearance and finish of the topcoats. Primer surfacers are spray applied. The use of primer-surfacers should increase because they greatly enhance appearance. Primer-surfacer innovations include improvements in chip performance, reduced VOCs and water based primer surfacers. Two specific technologies that are beginning to take hold are:

- *color-keyed primer-surfacers:* the color of the primer surfacer is coordinated with that of the basecoat to improve overall color "depth." Three or four primer surfacer colors (light-gray, dark-gray or a reddish color) are typically matched to the color of topcoat.
- *color-specific areas:* each basecoat color has a specific primer color for areas such as the underside of trunk lids or engine compartments. Hence, in these areas the manufacturer does not have to apply basecoat over the basecoat colored primer. This has a number of advantages including good aesthetic appearance, cost savings and a reduction in reject rate because the trunk and hood do not need to be opened when the topcoat is applied.

Topcoats

The differing and stringent demands made by users have led to the development of a number of differing topcoat technologies. There are two basic types of topcoat systems: monocoat systems and basecoat/clearcoat systems. Additionally, there are two types of automotive paints: solid colors and metallics. Metallic coatings account for 60 to 70% of automotive colors due to their enhanced gloss, aesthetic appeal and durability.

The increasing popularity of automotive metallic finishes in the 1970s led to basecoat/clearcoat technology replacing the one-coat system. However, traditional monocoats are still used in some assembly plants. The trend in these solvent borne monocoats is to reduce VOC levels, because it is unlikely that monocoats will transition to being aqueous based. Several manufacturers are eliminating monocoats entirely and going to basecoat/clearcoat systems.

Within basecoat//clearcoat systems, water borne basecoats are increasingly replacing solvent borne basecoats. The trend in water borne basecoats is to reduce VOCs, either through increased solids or replacing solvents with water. Clearcoat developments include improved "environmental etch" resistance, scratch/mar resistance, durability and gloss retention. A major breakthrough in clearcoat technology is the replacement of two-component clearcoats with one-component systems. Powder clearcoats are also being pursued actively. Presently, the major issue with powder clearcoats is that the temperature required for curing is higher than the current automotive bake temperatures. In addition, higher film builds are required to achieve appearances comparable to those of liquid coatings.

3.2 Process Based Cost Modeling

The painting process was viewed to consist of thirteen unit operations. Within each unit operation the costs were broken down into the elements discussed below.

Variable Costs

Variable cost elements are the contributions to piece cost whose values are independent of the number of elements produced. The variable cost elements appropriate for the painting process are:

Cost of Material

The cost of material takes into consideration the transaction price of the materials, mainly paints, that are used in the unit operation and the amount of material that is consumed. Paint consumption refers to total paint consumed, including that used for cars that might be rejected later.

Cost of Direct Labor

The cost of labor is a function of the wages paid, the time required for each operation, the number of laborers associated with the operation, and the productivity of this labor. Labor wages include the cost of benefits to the laborer. However, the costs associated with supervisors, janitors and support staff in general are accounted separately as overhead labor costs.

Cost of Energy

The predominant consumption of energy in painting is in the ovens. Ideally, it would be useful to have functional relationships that could be used to compute energy consumption as a function of oven temperature within the model. This would enable the user to evaluate the economic implications of using paints with lower curing temperatures. However, this is a complex task, and is beyond the scope of this thesis. Energy consumed, both gas and electric, for each step was obtained from assembly plants. Total energy costs would depend on the price of gas and electricity which may vary with the geographic location of the plant.

Cost of Waste Disposal

Waste disposal costs refer to the disposal cost of the two significant types of waste generated during painting: VOCs and paint sludge[19,20]. Paint sludge can be disposed as either hazardous or non-hazardous waste, depending on its content. In several plants, even though the sludge is non-hazardous it is disposed off as hazardous to limit liability in the future. In a few plants, including Chrysler, paint sludge is being recycled. However, recycling is not as prevalent as might be expected. Currently, the economics of treating sludge is such that it is cheaper to send it to landfills than to recycle it.

VOCs are generated during paint spraying in the booths, baking in the ovens and from solvents used to clean equipment and flush paint lines. The air from spray booths goes through water scrubbers to remove overspray paints before being sent for incineration. For solvent borne paints, most solvents are not captured in the scrubber water because of their low solubility in water and high volatility. VOC concentrations in exhaust air from a spray booth are very low (50-200 ppm typically) because of the large volumes of air used. Generally, an assembly plant uses an air flow rate of 1,200,000 scfm. Each 1,200,000 cubic feet of the exhaust air contains less than one gallon of solvent. Treatment of this huge volume of air that has low VOC concentrations makes VOC removal very expensive[21]. In general, the exhaust is incinerated at approximately

1400*F to destroy the VOCs. In some plants, activated carbon wheel absorbers are also used in VOC treatment. VOCs from large volumes of the booth exhaust air are adsorbed by carbon and then desorbed into a small amount of hot air, thus increasing the concentration of VOCs and decreasing the air volume to be incinerated. The current trend is to use a large incinerator rather than to use multiple small ones.

Normally all the exhaust air does not need to be treated to meet VOC regulations. The objective is to achieve VOC reduction to a predetermined amount to be in compliance and therefore, only certain stacks are selected for treatment. This decision is based not only on the emissions rate from each stack, but also on the location of the stack to be treated relative to that of the pollution control treatment. The location affects duct lengths which should be as short as possible to reduce paint deposits, condensation and costs.

Fixed Costs

In contrast with the variable costs the fixed costs are those elements which are a function of the annual production volume. The common elements of fixed costs are:

Equipment Cost

Equipment cost refers to the cost of capital equipment for each unit operation. In the case of the ovens, the cost is estimated as a function of the length of the oven, because oven manufacturers frequently use this approach to price ovens. A consistent procedure to distribute equipment costs over the annual production volume is required to obtain costs on a per piece basis. In the current model, the total investment is amortized over a fixed period of years using an appropriate interest rate. The annual cost is then divided by the production volume to obtain the per piece cost.

In estimating the total investment, it is necessary to take into consideration equipment dedication. The extent of dedication of a machine to the production of a part determines the fraction of total annual cost that the part cost must include. The fraction is computed by the ratio of the time required to produce the part to the total equipment time available.

Auxiliary Equipment Cost

The procedure for estimating auxiliary cost assumes that the ratio of the auxiliary equipment cost to the equipment cost is constant. For the painting process, this assumption yields valid results.

Installation Cost
Installation cost refers to the cost of installing the primary and auxiliary equipment at the outset. It is typically a fixed percentage of the primary and auxiliary equipment cost and is amortized in the same fashion as the equipment costs.

Fixed Overhead Labor Cost
Overhead labor costs are the salaries of supervisors, managers, janitors etc., not directly associated with the painting process but required nevertheless.

Maintenance Cost
The cost of maintaining capital equipment is difficult to quantify precisely. Maintenance is often unscheduled and performed in response to problems, as they develop. An accurate estimation of maintenance costs would require prediction of these problems. A reasonable alternative is to treat maintenance costs as a fraction of the cost of capital equipment[22]. In many cases, the equipment suppliers are a good source of fractions that accurately reflect reality.

Cost of Capital
This is the interest portion of the annual payments on the primary and auxiliary equipment and installation. The annual payments are calculated as an annuity, using an appropriate interest rate and time period.

Building Cost
The cost of building space is estimated by the amount of space required and the price per square foot. The space required for a paint shop can be obtained from published sources regarding newly constructed assembly plants or data obtained from existing plants. Values for the price per square foot is obtained from industry sources.

This summarizes the various elements of fixed and variable costs involved in the complete estimation of painting cost per car. To estimate these cost elements, several process parameters are necessary. Two such parameters are the cycle time and the number of parallel streams. A number of factors can influence the cycle time, such as baking time or length of the oven, time to spray a car etc. Cycle time affects the fixed costs by establishing, for a production run, the amount of time required to complete the run and, therefore, the number of parallel processing streams required. The number of parallel processing streams can be estimated from the ratio of the cumulative cycle time for the production run to the amount of time available during the run. This ratio rounded up to the next integer value is the number of machines required to produce the desired volume of production.

The effect of the number of streams on the painting cost depends on whether the painting line is dedicated. With dedicated equipment, changes in the number of streams effect both the total capital investment and the fixed cost per car. However, if the number of streams does not change, fixed costs are not sensitive to changes in cycle time. As opposed to this, for non-dedicated equipment, fixed costs vary directly with cycle time.

The Cost Model

The model is built using a Lotus 1-2-3 spreadsheet, and is laid out as shown in exhibit 3-2 (see the appendix for the detailed model). The first section of the model is dedicated to user defined inputs. A host of input parameters are required to accurately estimate the

Figure 3-2: Model Lay Out

Inputs	**Processing Steps - 1..n**	**Output: Summary**
Painting Line Parameters	**Variable Costs**	**Factor Based Cost Breakdown**
Specifications for	Materials	Variable
1. Pretreatment	Labor	Material
2. E-coat Application	Energy	Labor
3. E-coat Bake & Cure	Waste	Energy
4. E-coat Insp. & Rework	**Fixed Costs**	Waste
5. Sealer Application	Equipment	Other
6. P-Surfacer Application	Auxiliary Equipment	Fixed Costs
7. P-Surfacer Bake & Cure	Installation	Equipment
8. P-Surfacer Insp. & Rework	Maintenance	Auxiliary Equipment
9. Basecoat Application	Fixed Overhead	Installation
10. Basecoat Dry	Cost of Capital	Maintenance
11. Clearcoat Application		Fixed Overhead
12. Clearcoat Bake & Cure		Cost of Capital
13. Clearcoat Insp. & Rework		Building
		Process Based Cost Breakdown
Exogenous Factors		Pretreatment
		E-Coat
		Sealer Application
		Primer Surfacer
		Topcoat
		Total Materials Usage
		Total Energy Usage
		Waste Generated

painting cost per car. At the outset, the user has to chose from the various options available for each unit operation. For example, for the basecoat operation, the user can choose either a solvent or an aqueous based paint system. Or in the case of the e-coat operation, the user can chose spray or dip application. Thereafter, a multitude of inputs such as paint consumption per car, cost of paint, transfer efficiency, solids content at application, labor requirement, capital investment, reject rates etc. etc. have to be provided for each unit operation.

After supplying the necessary inputs, the user can proceed to the summary sheet which provides a breakdown of cost by factor and process. The actual calculations are performed in the main body of the spreadsheet, in which a single page (defined as one screen width on the computer) is dedicated to each processing step. Fixed and variable cost calculations are performed for each processing step based on the inputs specified and on engineering and physical relationships.

The elegance of the model lies in its flexibility. The user specifies most of the inputs and can thereby examine any variation of the automotive painting process. The model serves as a tool to examine the economics of the painting process. The effect of variations in several input parameters on automotive painting costs can be easily analyzed.

The automotive painting cost model was employed to execute an economic analysis of the painting process. Individual elemental cost estimates for the different unit operations were calculated based on a set of input parameters that reflect industry averages rather than any single automotive manufacturing plant. Cost estimates are based on the assumption of dedicated equipment, i.e., the equipment is used to paint only the car under consideration. Thus the painting costs include the total annual cost of the equipment used.

Exogenous cost factors used are displayed in exhibit 4-1. All cost estimates are based on

Exhibit 4-1: Exogenous Cost Factors Used in the Automotive Paint Model

EXOGENOUS COST FACTORS		
Operating Days per Year	250	day/yr
Shifts per Day	2	shft/day
Hours per Shift	10	hr/shft
Capital Recovery Rate	12.0%	
Capital Recovery Period	10	years
Building Lifetime	20	years
Direct Labor Wage	$24.00	/hr
Building Space Cost Factor	$75.00	/sq ft
Electricity Price	$0.08	/kWh
Natural Gas Price	$4.00	/MBtu
Unscheduled Downtime	10%	
Variable Overhead	0%	
Auxiliary Equipment Cost	20%	of Cap. E.
Installation Cost	25%	of Cap&Aux
Maintenance Cost	5%	of Cap&Aux
Fixed Overhead Cost	35%	of Fix.Cost
Floorspace Requirement Factor	200,000	sq ft

a standard working period of 240 days, with two shifts of ten hours each. The equipment costs are amortized at 12% over a period of ten years. Labor cost is assumed to be $24 per hour. The fixed overhead cost is assumed to be 35%.

As a base case, a steel body-in-white was considered. The inputs specified are as follows:

Production Volume: 250,000/year

Solvent Based Red Paint

Electrostatic Spraying with Transfer Efficiencies between 70 and 80%

Line Speed: 28.5 ft/min

Using these inputs in the model, the cost of painting a car is estimated to be $330.

4.1 Factor Based Cost Components

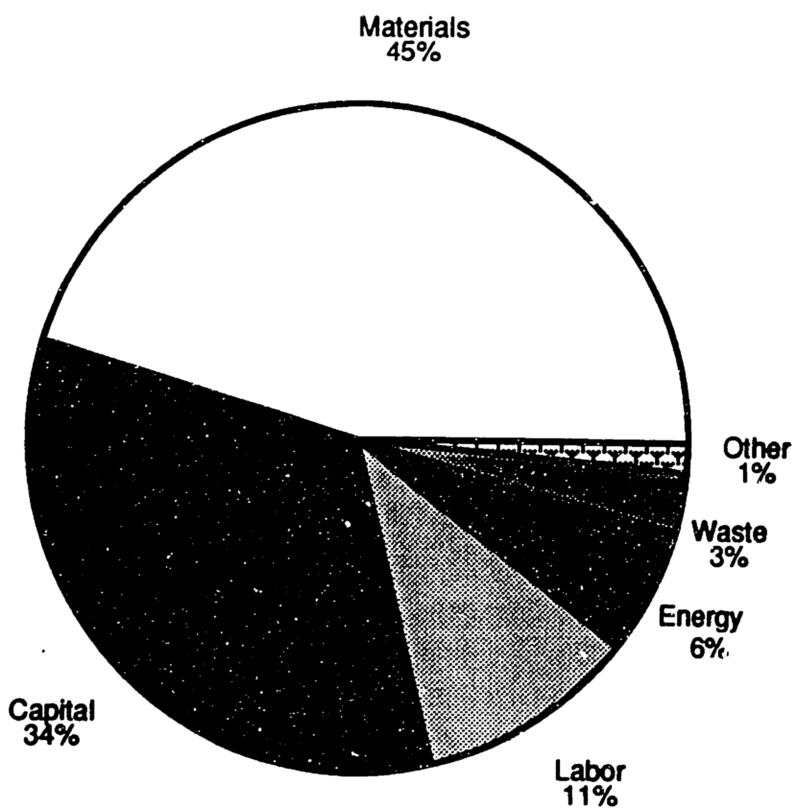
The total cost of painting a car is composed of material, capital, labor, energy, and waste treatment costs. Exhibit 4-2 displays the factor based cost components of automotive painting.

Materials account for the largest portion of automotive painting costs which is not surprising given the high cost of automotive paints. Material costs primarily consist of the cost of the e-coat, primer-surfacer, basecoat and clearcoat that are consumed. They depend on the cost of each of these paints and the paint consumption per car. The paint consumption per car is a strong function of transfer efficiency. As far as the e-coat is concerned, the transfer efficiency approaches almost 100% because the process involves dipping as opposed to spraying. However, for the application of the other three coats, currently, the best transfer efficiencies fall in the 70-80% range. One way to reduce material costs would be to improve transfer efficiencies.

Capital costs are the second largest contributor to painting costs. Painting is very capital intensive due to the equipment and space required for the various steps constituting the painting process. To reduce fixed costs per unit painted, high utilization of the painting line is essential. Large production volumes aid in achieving economies of scale by spreading the costs over several units. As the production volume increases, capital costs drop dramatically and consequently the total cost of painting a car also decreases. As is displayed in Exhibit 4-3, the cost of painting decreases from X for a production volume of Y to X for a production volume of Z.

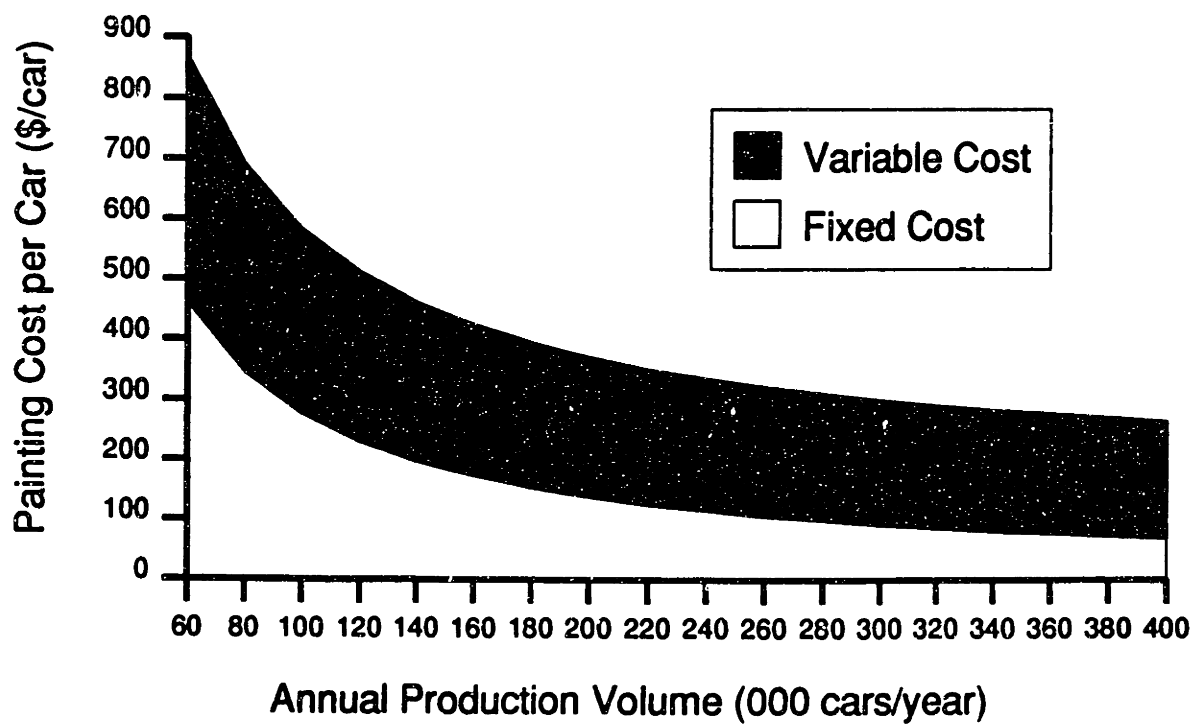
Exhibit 4-2: Factor Based Cost Components of Automotive Painting Costs

	Cost per Car ($)	Percentage of Total (%)
Materials	149	45.4
Capital	110	33.5
Labor	35	10.6
Energy	20	6.1
Waste	10	3.0
Other	4	1.4
Total	**328**	**100.0**



Due to these colossal capital costs, once a painting line has been installed, alterations cannot be easily justified unless they yield significant improvements in paint quality or economic advantages that outweigh the alteration costs. Research and development efforts in automotive painting need to consider constraints in implementation of new technologies due to capital costs. It is because of the capital intensity of the paint line that automotive design engineers, when modifying or changing car bodies have to bear in mind that the body-in-white should be able to go through the existing paint line. Most modifications or innovations to the painting process have been those that could be accommodated on existing paint lines.

Exhibit 4-3: Economies of Scale



Labor represents about 10% of automotive painting costs. There are variations across plants in the amount of labor used on paint lines. The most significant factor influencing labor is the level of automation and the design of the painting equipment. Consequently, the newer plants that are more automated tend to have less labor than the older plants. Most of the paint application operations are automated and require only one or two people to monitor and control the equipment, and ensure that there are no complications. The inspection and rework steps at various stages in the process are manual and require labor. In addition, sealer application is labor intensive because it requires accessing the nooks and crannies of each car. Automation of sealer application has been slow due to the physical complexity of the operation. There are some plants that have automated sealer application.

The energy costs primarily reflect energy consumption in ovens and air circulation. Approximately one-third of the electric energy and two-thirds of heating energy that is consumed in automotive plants is used in the paint shop. The concern with the heavy consumption of energy, from both a cost and an environmental perspective has led to the research and development of paints that can be baked and cured at lower temperatures or for shorter times[23].

Waste treatment costs account for about 3% of the painting costs. While this may not seem to be a significant proportion of the total cost, waste treatment and VOC reduction is a matter of concern for most plants. If the plants are in compliance, then the waste treatment costs are as stated. However, if a plant is out of compliance, the costs could increase dramatically due to fines or plant shut-downs. In addition, there are finite social costs in terms of the image of the company and relations with the community in case of non compliance.

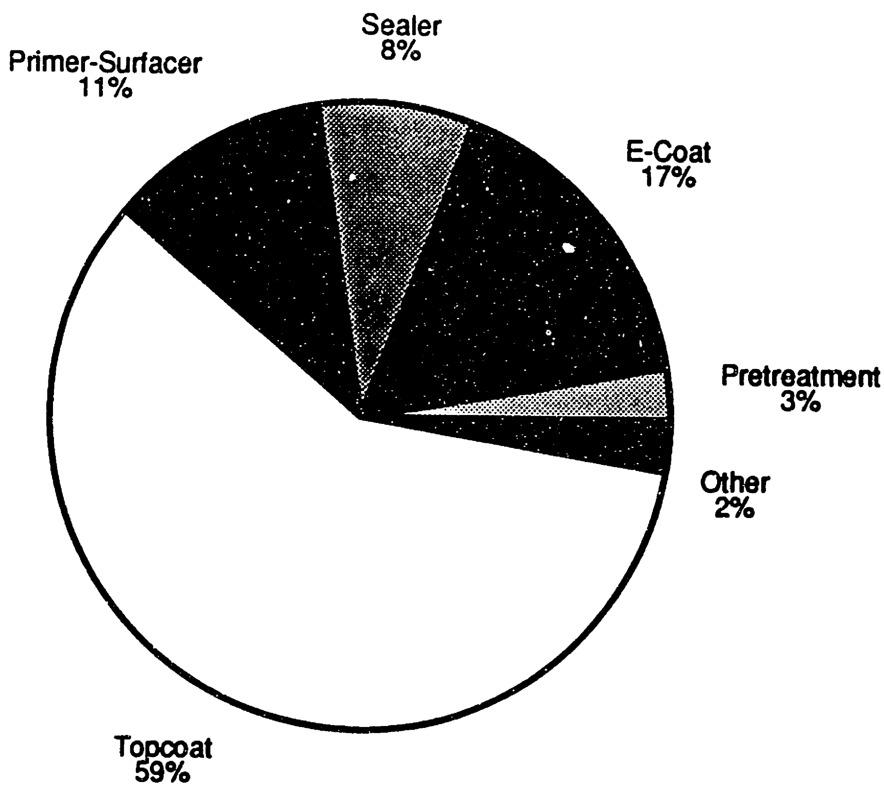
The 'other' category primarily includes the costs of the bodies-in-white that are rejected due to poor quality. It is calculated by considering the difference between the cost of the unpainted body-in-white and the salvage value of the reject. Under existing industry conditions this accounts for a mere 1% of the total costs of painting a car.

4.2 Process Based Cost Components

Exhibit 4-4 displays the process based components of automotive painting costs. The costs of automotive painting are viewed from the perspective of the five major

Exhibit 4-4: Process Based Cost Components of Automotive Painting Costs (dollars per car)

	Variable Cost($)	Fixed Cost($)	Total Cost($)	Percentage (%)
Pretreatment	2	7	9	2.6
E-Coat	24	31	55	16.5
Sealer	23	4	27	8.2
Primer-Surfacer	30	8	38	11.5
Topcoat	136	58	194	58.8
Other & Bldg.	5	3	8	2.3
Total	**220**	**110**	**330**	**100.0**



operations: Pretreatment, E-Coat, Sealer, Primer-Surfacer and Topcoat. As materials account for a significant portion of painting costs, it is expected that the step that is most material intensive would be the most expensive. The topcoat operation is the most expensive step in the painting process, accounting for 58.8% of the painting costs. Material usage in the form of the basecoat and the clearcoat, both of which are the most expensive automotive paints, account for this.

The ratio of fixed to variable costs for each of these steps varies depending on mainly their labor, material and capital content. Each of these steps is significant in obtaining a high quality paint job that will be durable. Pretreatment is crucial for corrosion prevention even though it is the least expensive. The topcoats determine the final gloss and appearance.

Environmental concerns, along with enhanced aesthetic requirements, are primarily driving the move to water borne paints. In the past, the coating industry attempted to meet environmental goals by continuously reducing VOCs in paint products. Toward this end, high solids coatings made significant progress by reducing solvent emissions approximately 50% as compared to previously available low solids coatings. However, this also caused a drop in the quality of basecoat appearance, because high solids coatings suffer from problems such as an orange-peel appearance and lack of sufficient gloss. Currently, further VOC reduction is not possible via high solid solvent basecoats, while their quality requires improvement. Water borne paints present an alternative technology that yields better quality and has the potential to reduce VOCs.

Exhibit 5.1: Water borne Basecoat Usage in North America
(Source: M.E. Rosenberger, SAE Technical Paper Series #930048)

Company	Plant	Model	Start-Up
General Motors	Oshawa Truck	CK Pick-Up	1987
	St. Therese	"A" body Cutlass Ciera	1989
	Wentzville	"H" body Bonneville Park Avenue, Ultra Delta 88	1990
	Lansing	Reatta Electric Car	1993
	Buick City	"H" body LeSabre, Delta 88	1991
	Lake Orion	"C" body Delta 98, DeVille	1992
	Spring Hill	Saturn	1991
Honda	East Liberty	4-door Civic	1989
Nissan	Smyrna	Ultima; Pick-Up	1992

The use of water borne paints in the US commenced in 1987[24]. Exhibit 5.1 lists the plants in North America where water borne basecoats are in use. Currently, a major drawback of water based paint is its low transfer efficiency. High transfer efficiencies in the paint process are attained via the use of electrostatic application. Though the electrostatic method of painting has existed for several years, it has not been possible to spray water borne paint electrostatically due to the high conductivity of water. However, due to recent breakthroughs, spraying water borne paints electrostatically is *gradually* becoming feasible[25]. Innovative methods include electrically isolating the paint gun from the rest of the paint line. Spraying electrostatically charged water borne coatings can improve transfer efficiencies from a non-electrostatic level of 25% to a range of 50 to 60%[26]. The Nissan Smyrna plant's Altima paint line uses an electrostatically charged water borne paint process for the basecoats with 15 second color changes at the line speeds[27].

The transfer efficiency determines how much paint sludge a facility will have to deal with. Paint sludge disposal is expensive because much of it is classified as hazardous. The more efficient the paint spraying process, the less the disposal costs due to a reduction in the paint sludge generated. An increase in transfer efficiency also implies that less paint is needed to meet standards and thus improves the economics. Increasing the transfer efficiency of water based paints reduces VOCs, sludge, chemical waste and paint consumption, and is therefore crucial for their usage to pervade.

While it is heavily touted that water based paints are environmentally friendly because of the lack of VOCs, this is currently not true. Presently, the transfer efficiencies of water based paints are not very high and they are applied at low solids (20-30%). Therefore, the amount of VOCs generated is almost comparable to those of high solid solvent base paints. However, they provide a promise of being environmentally friendly as advances in process technology increase the transfer efficiency and improvements in paint technology make higher solids water based paints possible. In Europe, where low solid solvent paints are popular, water based paints do provide a competitive edge because VOCs are lower when water based paints are employed compared to low solid solvent based paints[28].

The most significant advances in water based paints have been made in the arena of the basecoat. Water borne basecoat usage is escalating and is replacing solvent based basecoats in basecoat/clearcoat systems. Although basecoats were the first water borne developments, each type of automotive coating can potentially be converted to water borne. The primer-surfacer will be the next layer to transition to being water based. Several manufacturers are actively developing water borne primer-surfacers and they are already being supplied to several European automotive makers[29]. Water borne clearcoat prototypes are to be introduced by Akzo and IDAC (ICI's joint venture with DuPont) soon. However, it is predicted that powder may ultimately emerge as the dominant compliance technology for clearcoats[30].

Costs of Water vs. Solvent Basecoat

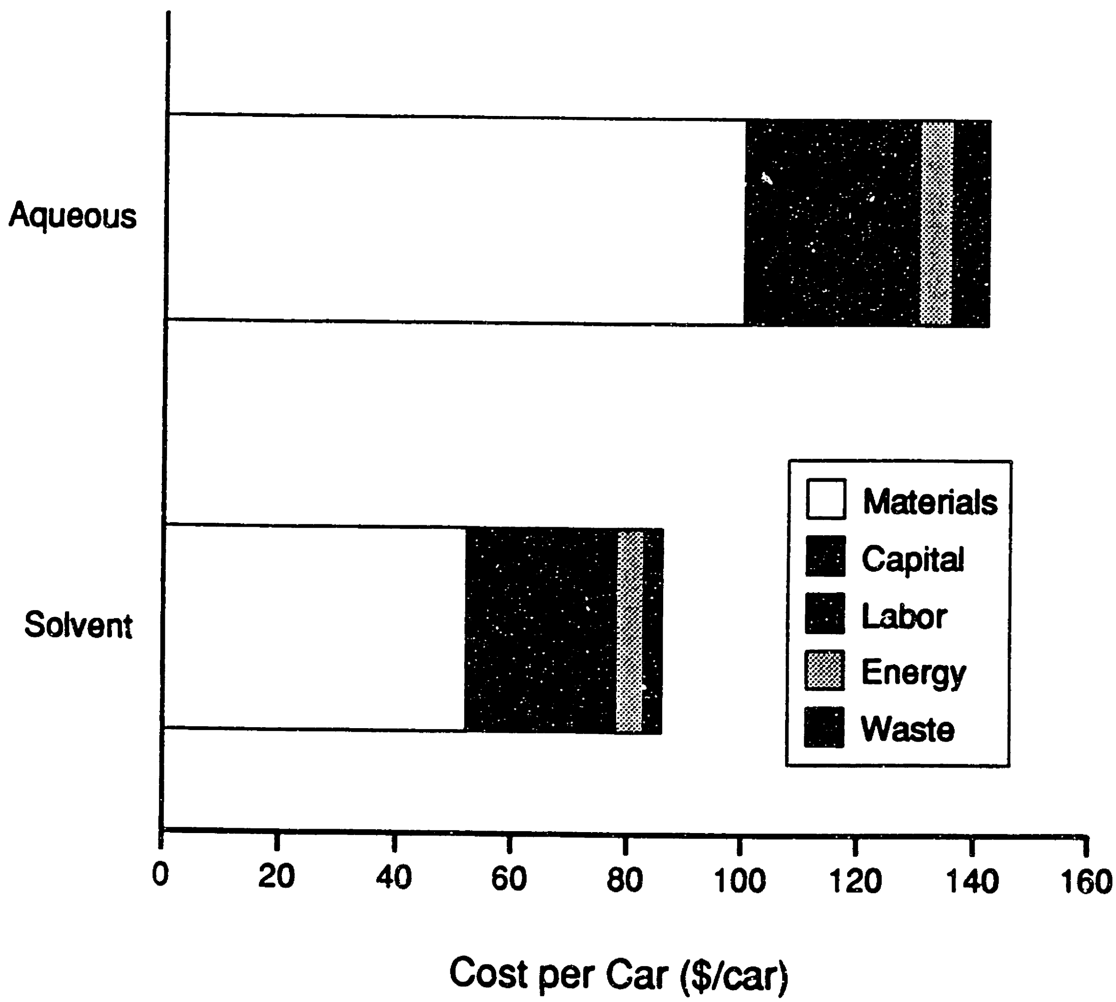
The basecoat is the layer which has most dominantly transitioned to being water based. Consequently, it was employed as a basis for an analysis of the economics of solvent versus aqueous coatings. Exhibit 5-1 displays a comparison of costs between a solvent and an aqueous basecoat. The major source of difference in costs is the cost of materials consumed. Material costs are higher for water based paints because more wet film is required for the same dry solids coverage. This is due to the lower transfer efficiency and lower solids (20-30%) of water based paints. Currently, the cost of aqueous paint per gallon is higher than that of solvent based paint of the same color and containing the same pigment. This is probably due to two reasons. The manufacturing costs of aqueous based paints are still high because manufacturers have not yet come down the learning curve; the technology is still being developed. Secondly, because it is a new product, the volume sold is not as high as that of existing solvent based paints, and therefore economies of scale are not being realized.

Capital costs for water borne paints are higher than those for solvent based paints for two reasons. Firstly, the piping and equipment in the case of water based paints has to be made of either stainless steel or plastic to prevent corrosion problems. Secondly, equipment is required for humidity and temperature control because the quality of the coating is sensitive to the humidity and temperature at the time of coating. It is conceivable that as VOC reductions are achieved, capital costs would decrease as less incinerators and other waste treatment equipment will be needed.

After the basecoat is applied, there is typically a flashoff oven to partially dry the basecoat before applying the clearcoat. In the case of water based paints a longer oven and more energy is required for this step because latent heat of water is higher than that of typical solvents. Consequently energy costs in the case of water based paints are somewhat higher than those in the case of solvent based paints.

Exhibit 5-1: Comparison of Solvent and Aqueous Basecoat Application and Drying Costs (dollars per car).

	Solvent		Aqueous	
	Cost ($)	**Percent (%)**	**Cost ($)**	**Percent (%)**
Materials	52	60.4	100	70.2
Capital	25	29.4	29	20.4
Labor	1	1.1	1	0.7
Energy	5	5.6	6	4.0
Waste	3	3.4	7	4.7
Total	**85**	**100.0**	**143**	**100.0**



It seems surprising that the cost of waste treatment in the case of aqueous systems is higher than that of solvent systems. The reasons for are two fold. Firstly, the VOCs generated in the case of aqueous systems can be comparable to or higher than those in the case of high solid solvent systems due to the lower transfer efficiency and percent solids of aqueous systems. In the cases studied, as demonstrated in Exhibit 5-2, the VOCs for the aqueous system were actually higher than those for the solvent system. Secondly, more sludge was generated in the aqueous system. This analysis did not take into account that the sludge might be concentrated before disposal, in which case the differences would not be as pronounced. Also the rates for the disposal of sludge in both cases were considered to be those for hazardous waste. This practice could vary from plant to plant, and if the aqueous sludge is regarded as non-hazardous, its disposal costs would be lower. At this stage, there is variation across the industry in practices for aqueous systems as the technology is relatively new.

Exhibit 5-2: VOC generation during painting - a comparison of aqueous and solvent basecoat systems (for similar dry film coverage).

	Solvent	**Aqueous**
Paint Consumed (gal/car)	0.5	1.5
Percent Solids in Paint (%)	50	30
VOCs in Paint (lbs/gal)	5.5	2.2
Transfer Efficiency (%)	70	40
VOCs Generated (lbs/car)	**2.75**	**3.3**
Sludge (gal/car)	**0.15**	**0.9**

It was assumed that the quality of the painting process is the same in both cases and hence the rejection rates are the same. The labor required also does not vary. Hence, there are no significant differences in labor, or 'other' costs between the two types of paint systems.

Chapter VI
Alternative Substrate Materials

The use of alternative substrate materials in car exteriors is intensifying. The most common replacements for conventional steel are various kinds of plastics, aluminum, and bake hardenable steels. In most cases these materials replace steel partially and cars constructed comprehensively of plastic or aluminum are rare. Bodies-in-white with mixed materials are becoming prevalent and they pose several challenges in the painting process.

Aluminum and plastic have specific issues in regards to the painting process that need to be regarded in the design of the car body. As mentioned earlier, the capital costs in setting up a paint line are significant, and hence modifications are not easy to make or justify. Consequently, in most cases very few changes can be made to the painting process to accommodate alternative materials. The constraints are generally on the car body design. Design engineers have to use materials that will conform to the requirements of the painting process. The most common changes made to the painting process in the case of plastics are temperature adjustments or, in cases wherein temperature adjustments are not feasible, alterations to the assembly process such as hanging the part on the car after the e-coat step or at the end. In the case of aluminum, typically the chemistry of pretreatment needs to be adjusted. Thereafter, it can go through the process in a fashion similar to steel.

This chapter discusses some of the painting issues that arise when aluminum or plastic form a part of the car body. Published sources and conversations with several industry personnel indicate that, currently, alternative substrate materials do not have a significant impact on the cost of automotive painting. They do pose challenges in terms of line start up and optimization. The implications of alternative materials for paint manufacturers are of relevance in decisions regarding research and development expenditures. For example, the invasion of plastics may necessitate developing paints that can be cured at lower temperatures.

6.1 Plastics

There has been considerable growth in the utilization of plastic materials in motor vehicles. Beyond the advantage in weight-savings, there are benefits in styling, resistance to minor damage, and corrosion resistance. They have traditionally been used for exterior components, such as bumpers, spoilers, wrap-arounds and ventilation grills. In addition their use for major body parts, such as door panels or bonnets, is increasing. The use of plastic causes problems in the painting process, such as adhesion, baking temperature limitations, solvent sensitivity and appearance matching.

Adhesion

Plastics generally have low levels of surface energy and therefore exhibit poor wettability for water and ordinary paint. Consequently, paint usually does not adhere well to plastic surfaces. It is especially difficult to get consistently adequate adhesion to some modified polypropylenes and special adhesion-promoting primers are necessary.

Heat Distortion

Plastic parts tend to warp or sag at elevated temperatures and need special treatment depending on their heat distortion temperature. The part may have to be painted entirely off-line (e.g. most polyurethane reaction injection molded parts) or it could be fitted after the electropainting oven (e.g. some PBT, glass-reinforced polypropylene, and most polyamides). Where painting is done off-line and the part is attached after the body-in-white has been through the paint line, color matching to the body is a challenge. In the case of some plastics that can withstand higher temperatures (e.g. some polyamides, SMC and related materials), the part can be fitted on to the body-in-white and go through the entire painting process just like steel. The only added step would be that the line and temperatures may need to be checked and optimized at the outset to ensure that the part can go through the process smoothly.

Surface Texture

The genuine appearance matching of different materials meeting in the same plane poses a challenging problem. One way manufacturers have tried to circumvent it is by using a common undercoat.

Solvent Sensitivity

Some plastics are affected excessively be solvents commonly used in painting causing crazing or degradation of mechanical properties. However, a mild degree of solvent attack can be beneficial.

Paint Flexibility

Many applications of plastic automotive parts require the parts to have pliancy and elasticity. Consequently, the paint film applied to such parts must be able to follow dimensional changes that occur without being damaged. If the paint film fails by cracking when the part is impacted or bent, there can be an induction of failure and the plastic part might crack. An unsuitable paint system can weaken the part and hence, the resin components making up the paint film must have a relatively high expansion rate.

Low Conductivity

Plastics such as SMC which can go through a regular paint line have to be coated with a conductive primer layer, because they are inherently non-conducting. This layer is essential for the plastic panels to undergo electrostatic painting. With the application of this layer, SMC becomes compatible with metal panels.

Exhibit 6.1: Relative advantages and disadvantages of plastic materials commonly used in automotives.

Plastic	Advantages	Disadvantages
Sheet Molded Compound (SMC)		
	high flex modulus	surface prone to waviness
	high distortion temperature	outgases on baking - topcoats bubble
	good solvent resistance	
Polyurethane: RIM and RRIM		
	wide range of moduli and toughness	variable porosity
		dimensional instability (expands when baked)
		solvent sensitivity (aggravated by glass fibers)
Injection Molded Plastics: Polycarbonate, ABS, Polyamide and Polypropylene		
	toughness and strength	some excessively brittle at lower temps
	good surface quality	some have low heat distortion temps
	wide range of flexibility	amorphous types are notch sensitive

The aforementioned problems have to be addressed in the design and painting of automobiles containing plastics. The biggest difference between the processes for steel and plastic lies in the baking temperatures. Electrodeposition paint is baked at approximately 180*C, whereas the primer-surfacers and topcoats are baked at 140*C. The heat distortion temperature for several plastic materials such as ABS, PMMA and polypropylene resins is lower than 140*C. This implies that it is necessary to reduce the curing temperature of painted resins as much as possible. In addition, the following characteristics are desirable in paints meant for plastics:

- They should be able to fill pinholes and cavities in the surface, that plastic materials typically tend to have.
- Primer paints must be capable of functioning as barriers to substances discharged from the plastic body due to heat or moisture and prevent them from reaching the topcoat. In order to avoid stains or discoloration, the topcoat should not react with low molecular weight substances that could be discharged from the plastic body.
- The paint should be flexible (have a low glass transition temperature and high expansion rate) in order to readily relieve stress due to impact or extension.
- The primer should be insensitive to material composition and should be capable of being applied to a wide variety of plastic materials. This is necessary to contain costs and reduce the complexity of painting plastics.

6.2 Aluminum

The Honda NSX, which was introduced in September 1990, initiated the use of aluminum for the body and parts of the chassis to the maximum extent possible in an attempt to reduce the weight of the car[31]. The main issue with the use of aluminum is that it poses a problem in the conventional pretreatment process. Zinc phosphate is typically used to pretreat steel. However, when zinc phosphate is applied to an aluminum surface, aluminum etches from the surface, becomes an ion and dissolves into the processing solution. As the aluminum ions accumulate in the processing solution, their concentration rises and hinders the formation of a zinc phosphate film on either aluminum or iron. Thus the zinc phosphate coating ability of the solution for both iron and aluminum is reduced. The use of chromium chromate helps alleviate this problem. However, the use of chromium presents hurdles due to governmental regulations because chromium is toxic and regarded as hazardous waste.

After the pretreatment step, aluminum can be treated in the same way as steel and does not require any special treatment. G. Courval and J. Allin of Alcan International argue and demonstrate that it is possible to eliminate the need for electrocoating aluminum because of its superior corrosion performance[32]. They recommend the use of alternate primers for the purpose of adhesion promotion, but state that the e-coat is not essential because its corrosion prevention property is not required. While this might be applicable in the case of a totally aluminum car body, it certainly does not hold in the case of mixed bodies-in-white and even a car like the NSX. The steel will always need to be protected, even though it may be only a small amount. Another consideration when aluminum is used is that of galvanic corrosion at and around the joints with dissimilar metals. In the case of the NSX this problem was treated by using grounding terminals.

Chapter VII
Implications of Strategic & Economic Analysis: Conclusions and Recommendations

The automotive paint industry is in a state of marked transition. The increased cost and quality consciousness of automotive manufacturers is intensifying their requirements of automotive paint suppliers. To respond to automotive manufacturers, and maintain competitiveness, it is crucial for paint suppliers to understand the economics of automotive painting, and be able to readily evaluate the impact of process changes and alternate technologies on automotive painting costs. Process based cost estimation provides a useful methodology to estimate automotive painting costs. It provides an understanding of the economics of the painting process by providing both, a factor and a process based cost breakdown. Moreover, it enables the user to evaluate the impact of process changes and alternate technologies on painting costs.

Materials (i.e. paints) and capital are the two major contributors to automotive painting costs. Materials form a substantial portion of painting costs (45%) and therefore, the pressure on paint suppliers from automotive manufacturers to reduce margins will probably continue to escalate. The high capital costs imply that subsequent to the installation of a painting line, alterations will not be made casually; they must yield significant improvements in quality or provide cost reductions that outweigh the alteration costs. This has to be kept in perspective when paint manufacturers engage in research and development.

In addition to pressure from automotive manufacturers, the automotive paint industry is being significantly influenced by government regulation; primarily, environmental considerations in the form of the Clean Air Act Amendments, and the changing materials mix in automotive bodies due to increased fuel efficiency standards. To respond to environmental considerations, automotive manufacturers are transitioning from solvent to aqueous systems. Currently, aqueous based systems are not necessarily environmentally superior to solvent based systems. When replacing low solid solvent systems, which are predominantly used in Europe, the use of aqueous systems does result in a significant reduction in VOC emissions. On the other hand, when replacing the high solid solvent systems that are popular in the United States, aqueous systems do not offer environmental benefits, mainly due to their low transfer efficiencies. However, aqueous technology is still in a nascent stage and there is significant room for improvement. It is due to this promise, and to the quality premium provided by aqueous paints compared to high solid solvent paints, that automotive manufacturers are continuing to adopt aqueous systems. Presently, aqueous systems are more expensive than comparable solvent based systems. However, their superior quality, environmental considerations, as well as a promise of lower costs in the future via technology development is motivating their use.

In response to CAFE regulation, weight reduction is becoming the single most important means to increase fuel economy as auto makers reach technical limits with alternate approaches. Consequently, steel is being replaced by lighter weight materials such as aluminum and various polymeric materials in automotive exteriors. The changing materials mix in automotive bodies will not significantly impact the economics of painting in the short term. The capital investment in automotive painting lines is too prohibitive to allow casual changes. In addition, there are also technological limitations in terms of the paint and process technologies currently available. For example, even though paints that cure at lower temperatures are desirable for plastics, low temperature curing paints with performance comparable to existing paints are not available. Currently, the impact of mixed materials in the body-in-white is adjustments to the painting process. Aluminum requires adjustment of the pretreatment step, while plastics require temperature adjustments, or painting off-line and subsequent assembly with color match to the body-in-white. Alternative materials have limited cost implications, basically the resources spent on paint line optimization and possibly increased rejection rates if there are quality issues. However, paint manufacturers need to consider the disparate painting requirements for alternative materials since their usage is on the rise.

Recommendations

As materials constitute a considerable portion of painting costs, paint suppliers will continue to experience increasingly stringent demands from automotive manufacturers to reduce margins while improving quality. To maintain their competitive positions in the industry, paint suppliers will have to be not only responsive to the existing needs of their customers, but also proactive in presenting solutions to persistent problems. In addition to cost and quality improvements specifically in paints, paint suppliers can respond by presenting alternatives to automotive manufacturers that reduce the overall cost per car painted. This is possible by being involved and thereby identifying sources of improvement in the painting process as a whole; for example, improvements in paint application technology would reduce costs by reducing the rejection rate.

A recent trend is for paint suppliers to work in conjunction with the auto companies to develop paint application technologies, in addition to the paint itself. This results in the paint company selling a service as opposed to a product, and provides a window on differentiation and value added services. For example, to distinguish itself, DuPont has been striving to develop technologies for the application of water-based paints. PPG is focusing on the sale of paint service as opposed to just the paint. Paint manufacturers need to continue and pursue this approach, working with both automotive manufacturers and paint equipment manufacturers to improve the overall painting process along both, cost and quality axes. They can ensure competitive positions by being proactive in the relationship they have with automotive manufacturers, in addition to presenting technological solutions

Automotive manufacturers are increasingly using process changes to attain improvements in paint quality. For example, Mazda recently introduced a novel paint coating technology known as 'Hi-Reflex' coating, which involves spinning the car through 360° in a paint oven, as if on a rotisserie[33]. The result is that the paint dries evenly and smoothly, particularly on vertical surfaces like the door and side panels. It addresses the problem conventional painting technology has had with achieving consistent quality and smoothness on vertical surfaces, especially with thick, high solids paint.

If one factor had to be identified as the key driver in this industry, it would be environmental regulation. Clearly, it is causing a move away from the traditional solvent based paints that automotive paint manufacturers have specialized in to alternate greener technologies. To retain competitiveness, automotive paint manufacturers need to position themselves strategically to keep abreast of technological change. Corporations that invest heavily in acquiring or developing environmentally safe solutions to the current solvent based systems will have a strategic advantage over time. Development of technology can be done in-house, via acquisitions and joint ventures, or by licensing. For example. DuPont has formed alliances with ICI in Europe (water borne coatings) and Glidden in the US. (powder coatings) to round out its product line. Akzo, BASF and PPG have licensed Union Carbide's Unicarb system, which replaces much of the solvents in paint formulations with supercritical carbon dioxide and is another new environmentally safe technology.

In addition to aqueous based paint systems, paint suppliers are pursuing powder coatings due to their negligible emissions, as a viable, environmentally safe alternative to solvent based paint systems. It is expected that issues currently limiting widespread usage of powder coats, primarily baking temperatures and equipment cost, will largely be resolved in the near future. The first production-line powder coated clearcoats are likely to become a reality by 1997 or 1998 according to PPG Industries, Strongsville, Ohio[34]. PPG has powder clearcoated several cars, which are being tested in use. In addition to environmental reasons, the exposure properties and appearance of powder clearcoats are reported to be excellent. Powder clearcoats are thicker then liquid clearcoats and hence provide a unique "depth" appearance.

Another environmentally friendly alternative to solvent based paint systems are paint films[35]. They involve covering plastic and metal parts with preformed multilayer films that perform the function of traditional coatings, that is, protection and decoration. They offer significant advantages over spray applied paints, including, reduced solvent emissions, fewer manufacturing steps and potentially lower coating costs.

The use of alternative materials in automotive bodies is also influencing automotive painting technology and the industry. For example, the influx of plastics into car bodies necessitates innovative paint technologies. Akzo Coatings, Troy, Michigan has been addressing the problem of coating plastics, and recently developed a novel coating that directly adheres to thermoplastic olefins without the need for tie coats or mechanical pretreatments[36]. In addition, auto-makers are also examining technologies such as mold in color for plastic parts that totally displace the painting step.

In summary, the evolution of the automotive painting industry is dependent on the growth of the automotive industry. Therefore, paint companies have to continue to be responsive to the needs of their customers. It is unlikely that the existing paint suppliers will face competition from companies entirely unfamiliar with the industry. However, entry by chemical companies actively involved with the development of new related technologies is not unforeseeable. Fundamental changes in technology might yield substitutes that replace or seriously modify contemporary painting technology. The prevailing industry leaders need to consistently monitor the market, and remain technologically competitive.

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33 Automotive Industries, June 1992 Page 30.
34 Industrial Finishing, December 1992, Page 17.
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36 Chemical Week, Sept. 9, 1992.

A copy of the process based cost estimation model (Lotus 123 Spreadsheet) for automotive painting is attached.

Press Alt-G To Find Outputs ========== ========== ==========

AUTOMOTIVE PAINT COST MODEL

Materials Systems Laboratory, MIT

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COMPONENT SPECIFICATIONS

Surface Area to be Painted	400	ft2/pc	SAREA
Value of Substrate	$400	/pc	SUBS
Production Volume	250	000/yr	NUM
Salvage Value of Substrate	100	/pc	SALV

LINE SPECIFICATIONS

Paint Line Speed	28.5	ft/min	SPEED
Spacing Between Hangers	2	ft	SPACE
Pieces per Hanger	1		PPH
Hanger Occupancy Rate	80%		OCCU
Dedicated Prime/Paint Line (Y/N)	1	(1=yes,0=no)	DED

PROCESS SPECIFICATIONS & PARAMETERS

----

1. PRETREATMENT	1	(1=Yes,0=No)	PRETREAT
Number of Cleaning Stages	2		
Number of Water Rinse Stages	3		
Zinc Phosphate Rinse (Y/N)	1	(1=yes,0=no)	
Chromic Acid Rinse (Y/N)	1	(1=yes,0=no)	
Spray Nozzles per Stage	150		
Zinc Phosphate Consumption	300	sq ft/gal	
Chromic Rinse Consumption	300	sq ft/gal	
Cleaner Concentration	2.0	oz/gal	
Spray Volume per Nozzle	3	gal/min	
Effective Water/Cleaner Recycled	99%		
Time in Each Cleaning Stage	1	min	
Time in Each Rinse Stage	1	min	
Drain Time between Stages	0.2	min	
Drain Time between Rinse and Dryer	1	min	
Time to Dry	4	min	
Time to Cool Down	4	min	
Number of Direct Laborers	2		
Cleaning Solution Temperature	150	°F	
Rinse Temperature	120	°F	
Ambient Cleaning Soln Temperature	140	°F	
Ambient Rinse Temperature	110	°F	
Energy Efficiency of Washer	95%		

Energy for Pumps	11	kW/stage
Price per Foot of Wash/Rinse	$20,000	/ft
Price per Foot of Dryer	$3,000	/ft
Price per Foot of Conveyor	$700	/ft
Zinc Phosphate Rinse Price	$0.200	/gal
Chromic Acid Rinse Price	$0.200	/gal
Water Price	$0.002	/gal
Cleaner Price	$0.070	/gal

ELECTROCOAT APPLICATION

Select Electrocoat Technology ========>	2	<menu>	PRIME
0. NONE			
1. Wet Spray	(WET)		
2. Electrophoretic Tank Dip	(ELPO)		

	WET	ELPO
2. Electrocoat Application		
E-Coat Consumption Rate [gal/car]	NA	1.5
Transfer Efficiency	NA	100.0%
E-coat Price, 100% Solids [$/gal]	NA	$50.00
Solvent Price [$/gal]	$0.01	$0.01
Solids Content [by vol]	NA	20.5%
Booth/Tank Capital Invest [$000]	NA	$20,000
Labor Requirement [men/stn.]	NA	2
Filter Waste [lbs/unit]	NA	2
VOC per gal of Electrocoat [lbs/gal]	0.6	0.6
Application Time/Part [min]	NA	2
Elec. Consumption by Pumps [kW]	0	200
3. Electrocoat Dry & Cure		
Dry & Cure Cycle Time [min]	30	30
Electric Energy Consumption [kW]	0	0
Gas Energy Consumption [MBtu/hr]	50	50

Price per Foot of Dry/Cure Oven	$6,000	/ft
Length of Dry/Cure Oven <optional>	0	ft

4. Electrocoat Inspection & Rework

Note: Rejected parts are reworked by manually spraying then recycling through the dry/cure oven.

1st Pass Rejection Rate	0.0%	P1REJECT
2nd Pass Rejection Rate	0.0%	P2REJECT
3rd Pass Rejection Rate	0.0%	P3REJECT
Touch-up Application Rate	100.0%	of primed surface

Touch-up Cycle Time	15	mins	
Number of Direct Laborers	1	/stn	
Rework Booth Capital Investment	$250,000		

5. SEALER APPLICATION	1	(1=Yes,0=No)	SEAL

SEALER CONSUMPTION

	Usage [gal/car]	Cost [$/gal]
Anti-Flutter Material	0.25	$15
Body Panel Reinforcement	0.2	$10
Generic Sealer	0.55	$5

Labor Requirement [men/stn.]	30
Capital Investment [$000]	$3,000
Sealer Waste [%]	1.0%
Sealer Waste Treatment Cost [$/gal]	$5
VOC per gal of Sealer [lbs/gal]	0.25

PRIMER-SURFACER APPLICATION

Select Technology =======>	1	<menu>	PRIMSUR
0. None			
1. Solvent Based	(SOLVENT)		
2. Aqueous Based	(AQUEOUS)		
3. Powder	(POWDER)		

6. Primer-Surfacer Application	SOLVENT	AQUEOUS	POWDER
P-Surfacer Consumption [gal/car]	0.4	0.5	NA
Cured Paint Thickness [mils]	1	1	2
Transfer Efficiency	70.0%	40.0%	100.0%
Surfacer Price, 100% Solids [$/gal]	$50.00	$45.00	$120.00
Solvent Price [$/gal]	$3.00	$0.01	NA
Solids Content [by vol]	50.0%	30.0%	99.5%
Spray Booth Capital Invest [$000]	$1,500	$1,500	NA
Labor Requirement [men/stn.]	25	3	3
Solids Applied to Car [gal/car]	0.14	0.06	NA
VOC per gal of Surfacer [lbs/gal]	5.5	1.0	0.0
Application Time/Part [min]	2	3	4
7. Primer-Surfacer Dry & Cure			
Dry & Cure Cycle Time [min]	30	30	NA
Electric Energy Consumption [kW]	0	0	0
Gas Energy Consumption [MBtu/hr]	50	50	NA

Price per Foot of Dry/Cure Oven	$6,000	/ft
Length of Dry/Cure Oven <optional>	0	ft

8. Primer-Surfacer Inspection & Rework

Note: Rejected parts are reworked by manually spraying then recycling through the dry/cure oven.

1st Pass Rejection Rate	0.0%	S1REJECT	
2nd Pass Rejection Rate	0.0%	S2REJECT	
3rd Pass Rejection Rate	0.0%	S3REJECT	
Touch-up Application Rate	100.0%	of painted surface	
Touch-up Cycle Time	15	mins	
Number of Direct Laborers	1	/stn.	
Rework Booth Capital Investment	$1,500,000	$1,500,000	$1,500,000

TOPCOAT APPLICATION

The topcoat can be a monocoat or a basecoat/clearcoat system. To choose a monocoat system, select "none" for basecoat application and drying.

Select Basecoat Technology ========>	1	<menu>	BASE
0. None			
1. Solvent Based	(SOLVENT)		
2. Aqueous Based	(AQUEOUS)		

	SOLVENT	AQUEOUS
9. Basecoat Application	------------------	------------------
Basecoat Consumption [gal/car]	0.5	1.5
Cured Paint Thickness [mils]	NA	NA
Transfer Efficiency	70.0%	40.0%
Paint Price, 100% Solids [$/gal]	$200.00	$220.00
Solvent Price [$/gal]	$3.00	$0.01
Solids Content [by vol]	50.0%	30.0%
Spray Booth Capital Invest [$000]	$20,000	$22,000
Labor Requirement [men/stn.]	2	2
VOC per gallon of paint [lbs/gal]	5.5	2.2
Application Time/Part [min]	2	2
Solids Applied to Car [gal/car]	0.18	0.18
VOCs Generated per Car [gal/car]	2.75	3.3
10. Basecoat Dry		
Drying Cycle Time [min]	2	10
Energy Consumption [kW]	0	0
Energy Consumption [MBtu/hr]	50	60

Price per Foot of Dry/Cure Oven	$6,000 /ft
Length of Dry/Cure Oven <optional>	0 ft

Select Clearcoat Technology =======> 1 <menu> TOP

1. Solvent Based (SOLVENT)
2. Aqueous Based (AQUEOUS)
3. Electrostatic Powder Spray (POWDER)

	SOLVENT	AQUEOUS	POWDER
11. Clearcoat Application			
Clearcoat Consumption [gal/car]	0.5	NA	NA
Cured Paint Thickness [mils]	2	1	3
Transfer Efficiency	70.0%	40.0%	NA
Paint Price, 100% Solids [$/gal]	$250.00	$200.00	$120.00
Solvent Price [$/gal]	$3.00	$3.00	NA
Solids Content [by vol]	43.5%	80.0%	99.5%
Spray Booth Capital Invest [$000]	$20,000	$20,000	NA
Labor Requirement [men/stn.]	2	2	3
VOC per gallon of paint [lbs/gal]	4.0	1.0	0.0
Application Time/Part [min]	2	3	4
12. Clearcoat Dry & Cure			
Dry & Cure Cycle Time [min]	30	30	NA
Energy Consumption [kW]	0	0	0
Energy Consumption [MBtu/hr]	50	50	NA

Price per Foot of Dry/Cure Oven	$6,000 /ft
Length of Dry/Cure Oven <optional>	0 ft

13. Clearcoat Inspection & Rework

Note: Rejected parts are reworked by manually spraying then recycling through the dry/cure oven.

1st Pass Rejection Rate	10.0%	T1REJECT
2nd Pass Rejection Rate	15.0%	T2REJECT
3rd Pass Rejection Rate	100.0%	T3REJECT

Touch-up Application Rate	100.0% of painted surface
Touch-up Cycle Time	15 mins
Number of Direct Laborers	10 /stn.
Rework Booth Capital Investment	$1,500,000

WASTE TREATMENT

Non Hazardous Sludge Treatment Cost	$5	/gal	
Hazardous Sludge Treatment Cost	$8	/gal	
Treat sludge as hazardous?	1	1=Yes, 0=No)	
Sludge Cost Used for Calculations	$8		HSLUDGE
Cost of Incinerators	$25	/SCFM	INCIN
Incinerator Capacity Desired	120,000	SCFM	INCINCAP
Labor Requirement [men/stn.]	4		
Cleaning/Purging Solvents Used	5	lbs/unit	
Percent Recycled	80%		

EXOGENOUS COST FACTORS

Operating Days per Year	250	day/yr	DAY
Shifts per Day	2	shft/day	SHFT
Hours per Shift	10	hr/shft	HRS
Capital Recovery Rate	12.0%		CRR
Capital Recovery Period	10	years	CRP
Building Lifetime	20	years	BLIFE
Direct Labor Wage	$24.00	/hr	WAGE
Building Space Cost Factor	$75.00	/sq ft	RENT
Electricity Price	$0.08	/kWh	ELEC
Natural Gas Price	$4.00	/MBtu	GAS
Unscheduled Downtime	10%		DOWN
Variable Overhead	0%		VOH
Auxiliary Equipment Cost	20%	of Cap. E.	AUX
Installation Cost	25%	of Cap&Aux	INST
Maintenance Cost	5%	of Cap&Aux	MNT
Fixed Overhead Cost	35%	of Fix.Cost	OVHD
Floorspace Requirement Factor	200,000	sq ft	BUILD1

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Press Alt-G To Find Outputs

PRETREATMENT COST CALCULATIONS

Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per Piece	Annual	Percent	
Material Cost	$0.42	$104,017	4.8%	
Labor Cost	$0.96	$240,000	11.1%	
Energy Cost	$0.64	$160,000	7.4%	
Variable Overhead	$0.00	$0	0.0%	
Waste Treatment Cost	$0.00		0.0%	
TOTAL VARIABLE COST	$2.02	$504,017	23.4%	
FIXED COST ELEMENTS	Per piece	Annual	Percent	Investment
Equipment	$2.14	$535,914	24.9%	$5,359,140
Auxiliary Equipment Cost	$0.43	$107,183	5.0%	$1,071,828
Installation Cost	$0.64	$160,774	7.5%	$1,607,742
Maintenance Cost	$0.13	$32,155	1.5%	
Fixed Overhead	$0.95	$236,338	11.0%	
Cost of Capital	$2.32	$580,115	26.9%	
TOTAL FIXED COST	$6.61	$1,652,479	76.6%	
TOTAL COST	$8.63	$2,156,496	100.0%	

ADDITIONAL INFORMATION

Operation Throughput (incl rejects)	253,807	pcs/yr
Number of Cleaning Stages	2	
Number of Rinse Stages	5	
Washing/Rinsing Time	8	min
Drying Time	4	min
Total Prep. Cycle Time	17	min
Length of Wash/Rinse	234	ft
Length of Dryer Tunnel	114	ft
Length of Conveyor	490	ft
Number of Direct Laborers	2	/stn
Zinc Phosphate Consumption	0.67	gal/pc
Chromic Acid Rinse Cons.	0.67	gal/pc
Water Consumption	46.13	gal/pc
Cleaner Consumption	0.72	gal/pc

Energy Cons. in Pumping	400	kW
Utilization for One Stn.	6.6%	
Actual Utilization	1.0	
Number of Parallel Stn.	1	
Equip. Investment/line	$5,359,140	
Equip. Principal/Interest	$922,657	
Aux. Principal/Interest	$184,531	
Inst. Principal/Interest	$276,797	

Press Alt-G To Find Outputs

| Electrocoat APPLICATION COST CALCULATIONS

| Materials Systems Laboratory, MIT

VARIABLE COSTS	Per Piece	Annual	Percent	
Material Cost	$15.62	$3,905,311	36.5%	
Labor Cost	$0.96	$240,000	2.2%	
Energy Cost	$0.38	$96,000	0.9%	
Variable Overhead Cost	$0.00	$0	0.0%	
Waste Treatment Cost	$1.22	$304,569	2.8%	
TOTAL VARIABLE COST	$18.18	$4,545,879	42.4%	
FIXED COST ELEMENTS	Per piece	Annual	Percent	investment
Equipment	$8.00	$2,000,000	18.7%	$20,000,000
Auxiliary Equipment Cost	$1.60	$400,000	3.7%	$4,000,000
Installation Cost	$2.40	$600,000	5.6%	$6,000,000
Maintenance Cost	$0.48	$120,000	1.1%	
Fixed Overhead	$3.53	$882,000	8.2%	
Cost of Capital	$8.66	$2,164,954	20.2%	
TOTAL FIXED COST	$24.67	$6,166,954	57.6%	
TOTAL COST	$42.85	$10,712,834	100.0%	

ADDITIONAL INFORMATION

peration Throughput (incl rejects)	253,807	cars/yr	PREQUIRE
Electrocoat Price as Applied	$10.26	/gal	
Number of Direct Laborers	2	/stn	
Sludge/Filter Waste Generated	1.500	lbs/pc	
Time in Bath	2.0	min	
Min. Length of E-Coat Tank	57	feet	
Utilization for One Station	0.1		
Actual Utilization	1.0		
Number of Parallel Stn.	1		
Equip. Investment/Station	$20,000,000		
Equip. Principal/Interest	$3,443,303		
Aux. Principal/Interest	$688,661		
Inst. Principal/Interest	$1,032,991		

Press Alt-G To Find Outputs

| Electrocoat DRYING & CURING COST CALCULATIONS
| Materials Systems Laboratory, MIT

VARIABLE COSTS	Per Piece	Annual	Percent	
Material Cost	$0.00	$0	0.0%	
Labor Cost	$0.00	$0	0.0%	
Energy Cost	$4.80	$1,200,000	41.1%	
Variable Overhead Cost	$0.00	$0	0.0%	
Waste Treatment Cost	$0.54	$135,753	4.7%	
TOTAL VARIABLE COST	$5.34	$1,335,753	45.8%	
FIXED COST ELEMENTS	Per piece	Annual	Percent	investment
Equipment Cost	$2.05	$513,000	17.6%	$5,130,000
Auxiliary Equipment Cost	$0.41	$102,600	3.5%	$1,026,000
Installation Cost	$0.62	$153,900	5.3%	$1,539,000
Maintenance Cost	$0.12	$30,780	1.1%	
Fixed Overhead	$0.90	$226,233	7.8%	
Cost of Capital	$2.22	$555,311	19.0%	
TOTAL FIXED COST	$6.33	$1,581,824	54.2%	
TOTAL COST	$11.67	$2,917,577	100.0%	

ADDITIONAL INFORMATION

peration Throughput (incl rework)	253,807	parts/yr
Dry & Cure Cycle Time	30	min
Length of Drying Oven	855	ft
Number of Direct Laborers	0	/stn. (prev op)
Electric Energy Consumption	0	kW
Gas Energy Consumption	50	MBtu/hr
VOCs Generated	0.900	lb/pc
Utilization for One Station	0.1	
Actual Utilization	1.0	
Number of Parallel Stn.	1	
Equip. Investment/Station	$5,130,000	
Equip. Principal/Interest	$883,207	
Aux. Principal/Interest	$176,641	
Inst. Principal/Interest	$264,962	

Press Alt-G To Find Outputs

| Electrocoat INSPECTION & REWORK COST CALCULATIONS
| Materials Systems Laboratory, MIT

VARIABLE COSTS	Per Piece	Annual	Percent	
Material Cost	$0.00	$0	ERR	
Labor Cost	$0.00	$0	ERR	
Energy Cost	$0.00	$0	ERR	
Variable Overhead Cost	$0.00	$0	ERR	
Waste Treatment Cost	$0.00	$0	ERR	
TOTAL VARIABLE COST	$0.00	$0	ERR	
FIXED COST ELEMENTS	Per piece	Annual	Percent	investment
Equipment	$0.00	$0	ERR	$0
Auxiliary Equipment Cost	$0.00	$0	ERR	$0
Installation Cost	$0.00	$0	ERR	$0
Maintenance Cost	$0.00	$0	ERR	
Fixed Overhead	$0.00	$0	ERR	
Cost of Capital	$0.00	$0	ERR	
TOTAL FIXED COST	$0.00	$0	ERR	
TOTAL COST	$0.00	$0	ERR	

ADDITIONAL INFORMATION

Electrocoat Technology:	ELPO	
Touch-up Electrocoat Cons.	1.500	gal/pc reworked
Electrocoat Price as App.	$10.26	/gal
Number of Direct Laborers	1	/stn.
Utilization for One Stn.	0.0	
Actual Utilization	0.0	
Number of Parallel Stn.	0	
Equip. Investment/Station	$250,000	
Equip. Principal/Interest	$0	
Aux. Principal/Interest	$0	
Inst. Principal/Interest	$0	

Electrocoat OPERATION SUMMARY

Scrapped Pieces	0	parts/yr	PSCRAP
Throughput (inc rework & reject)	253,807	parts/yr	PTHRU
Number of Reworked Cycles	0	parts/yr	PREWORK
Scrap Ratio	0.000		
Rework Ratio	0.000		
Operation Output (good parts)	253,807	parts/yr	

Press Alt-G To Find Outputs

SEALER APPLICATION COST CALCULATIONS

Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$8.63	$2,157,360	31.8%	
Labor Cost	$14.40	$3,600,000	53.0%	
Energy Cost	$0.00	$0	0.0%	
Variable Overhead Cost	$0.00	$0	0.0%	
Waste Treatment Cost	$0.43	$107,868	1.6%	
TOTAL VARIABLE COST	$23.46	$5,865,228	86.4%	
FIXED COST ELEMENTS	**Per piece**	**Annual**	**Percent**	**investment**
Equipment Cost	$1.20	$300,000	4.4%	$3,000,000
Auxiliary Equipment Cost	$0.24	$60,000	0.9%	$600,000
Installation Cost	$0.36	$90,000	1.3%	$900,000
Maintenance Cost	$0.07	$18,000	0.3%	
Fixed Overhead	$0.53	$132,300	1.9%	
Cost of Capital	$1.30	$324,743	4.8%	
TOTAL FIXED COST	$3.70	$925,043	13.6%	
TOTAL COST	$27.16	$6,790,272	100.0%	

ADDITIONAL INFORMATION

Total Sealer Used	1.00	gallon
Total Sealer Cost	8.500	$/car
Number of Direct Laborers	30	/stn.
Energy Consumption	0	kW (next op)
Sealer Sludge Generated	0.085	gal/pc
VOCs Generated	0.25	lbs
Utilization for One Station	0.1	
Actual Utilization	1.0	
Number of Parallel Stn.	1	
Equip. Investment/Station	$3,000,000	
Equip. Principal/Interest	$516,495	
Aux. Principal/Interest	$103,299	
Inst. Principal/Interest	$154,949	

Press Alt-G To Find Outputs

| PRIMER-SURFACER APPLICATION COST CALCULATIONS

| Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent
Material Cost	$10.76	$2,690,355	42.1%
Labor Cost	$12.00	$3,000,000	46.9%
Energy Cost	$0.00	$0	0.0%
Variable Overhead Cost	$0.00	$0	0.0%
Waste Treatment Cost	$0.97	$243,655	3.8%
TOTAL VARIABLE COST	$23.74	$5,934,010	92.8%

FIXED COST ELEMENTS	Per piece	Annual	Percent	investment
Equipment Cost	$0.60	$150,000	2.3%	$1,500,000
Auxiliary Equipment Cost	$0.12	$30,000	0.5%	$300,000
Installation Cost	$0.18	$45,000	0.7%	$450,000
Maintenance Cost	$0.04	$9,000	0.1%	
Fixed Overhead	$0.26	$66,150	1.0%	
Cost of Capital	$0.65	$162,372	2.5%	
TOTAL FIXED COST	$1.85	$462,522	7.2%	
TOTAL COST	$25.59	$6,396,532	100.0%	

ADDITIONAL INFORMATION

peration Throughput (incl rejects)	253,807	parts/yr	SREQUIRE
Surfacer Consumption	0.400	gal/pc	
Surfacer Price as Applied	$26.50	/gal	
Number of Direct Laborers	25	/stn.	
Cycle Time	2.0	min	
Sludge Generated	0.120	gal/pc	
Utilization for One Station	0.1		
Actual Utilization	1.0		
Number of Parallel Stn.	1		
Equip. Investment/Station	$1,500,000		
Equip. Principal/Interest	$258,248		
Aux. Principal/Interest	$51,650		
Inst. Principal/Interest	$77,474		

Press Alt-G To Find Outputs

| PRIMER-SURFACER DRYING & CURING COST CALCULATIONS
| Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$0.00	$0	0.0%	
Labor Cost	$0.00	$0	0.0%	
Energy Cost	$4.80	$1,200,000	38.5%	
Variable Overhead	$0.00	$0	0.0%	
Waste Treatment Cost	$1.33	$331,841	10.7%	
TOTAL VARIABLE COST	$6.13	$1,531,841	49.2%	
FIXED COST ELEMENTS	**Per piece**	**Annual**	**Percent**	**investment**
Equipment Cost	$2.05	$513,000	8.0%	$5,130,000
Auxiliary Equipment Cost	$0.41	$102,600	3.3%	$1,026,000
Installation Cost	$0.62	$153,900	4.9%	$1,539,000
Maintenance Cost	$0.12	$30,780	1.0%	
Fixed Overhead	$0.90	$226,233	7.3%	
Cost of Capital	$2.22	$555,311	17.8%	
TOTAL FIXED COST	$6.33	$1,581,824	42.3%	
TOTAL COST	$12.45	$3,113,664	91.5%	

ADDITIONAL INFORMATION

peration Throughput (incl rework)	253,807	parts/yr
Dry & Cure Time	30	min
Length of Drying Oven	855	ft
Number of Direct Laborers	0	/stn. (prev op)
Electric Energy Consumption	0	kW
Gas Energy Consumption	50	MBtu/hr
VOCs Generated	2.200	lb/pc
Utilization for One Station	0.1	
Actual Utilization	1.0	
Number of Parallel Stn.	1	
Equip. Investment/Station	$5,130,000	
Equip. Principal/Interest	$883,207	
Aux. Principal/Interest	$176,641	
Inst. Principal/Interest	$264,962	

Press Alt-G To Find Outputs

| PRIMER-SURFACER INSPECTION & REWORK COST CALCULATIONS

| Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$0.00	$0	ERR	
Labor Cost	$0.00	$0	ERR	
Energy Cost	$0.00	$0	ERR	
Variable Overhead	$0.00	$0	ERR	
Waste Treatment Cost	$0.00	$0	ERR	
TOTAL VARIABLE COST	$0.00	$0	ERR	
FIXED COST ELEMENTS	Per piece	Annual	Percent	investment
Equipment	$0.00	$0	ERR	$0
Auxiliary Equipment Cost	$0.00	$0	ERR	$0
Installation Cost	$0.00	$0	ERR	$0
Maintenance Cost	$0.00	$0	ERR	
Fixed Overhead	$0.00	$0	ERR	
Cost of Capital	$0.00	$0	ERR	
TOTAL FIXED COST	$0.00	$0	ERR	
TOTAL COST	$0.00	$0	ERR	

ADDITIONAL INFORMATION

O

Touch-up Paint Consumption	0.400	gal/pc reworked
Touch-up Paint Price as Applied	$26.50	/gal
Number of Direct Laborers	1	/stn.
Energy Consumption	0	kW
Utilization for One Station	0.0	
Actual Utilization	0.0	
Number of Parallel Stn.	0	
Equip. Investment/Station	$1,500,000	
Equip. Principal/Interest	$0	
Aux. Principal/Interest	$0	
Inst. Principal/Interest	$0	

Sludge Generated	0.120	gal/pc	
Scrapped Pieces	0	parts/yr	SSCRAP
Throughput (inc rework & reject)	253,807	parts/yr	STHRU
Number of Reworked Cycles	0	parts/yr	SREWORK
Scrap Ratio	0.000		
Rework Ratio	0.000		
Operation Output	253,807	parts/yr	

Press Alt-G To Find Outputs

| BASECOAT APPLICATION COST CALCULATIONS
| Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$51.52	$12,880,711	65.7%	
Labor Cost	$0.96	$240,000	1.2%	
Energy Cost	$0.00	$0	0.0%	
Variable Overhead Cost	$0.00	$0	0.0%	
Waste Treatment Cost	$1.22	$304,569	1.6%	
TOTAL VARIABLE COST	$53.70	$13,425,279	68.5%	
FIXED COST ELEMENTS	**Per piece**	**Annual**	**Percent**	**investment**
Equipment Cost	$8.00	$2,000,000	10.2%	$20,000,000
Auxiliary Equipment Cost	$1.60	$400,000	2.0%	$4,000,000
Installation Cost	$2.40	$600,000	3.1%	$6,000,000
Maintenance Cost	$0.48	$120,000	0.6%	
Fixed Overhead	$3.53	$882,000	4.5%	
Cost of Capital	$8.66	$2,164,954	11.1%	
TOTAL FIXED COST	$24.67	$6,166,954	31.5%	
TOTAL COST	$78.37	$19,592,233	100.0%	

ADDITIONAL INFORMATION

peration Throughput (incl rejects)	253,807	parts/yr	O
Paint Consumption	0.500	gal/pc	
Paint Price as Applied	$101.50	/gal	
Number of Direct Laborers	2	/stn.	
Energy Consumption	0	kW (next op)	
Cycle Time	2.0	min	
Sludge Generated	0.150	gal/pc	
Utilization for One Station	0.1		
Actual Utilization	1.0		
Number of Parallel Stn.	1		
Equip. Investment/Station	$20,000,000		
Equip. Principal/Interest	$3,443,303		
Aux. Principal/Interest	$688,661		
Inst. Principal/Interest	$1,032,991		

Press Alt-G To Find Outputs

BASECOAT DRYING COST CALCULATIONS

Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$0.00	$0	0.0%	
Labor Cost	$0.00	$0	0.0%	
Energy Cost	$4.80	$1,200,000	69.8%	
Variable Overhead	$0.00	$0	0.0%	
Waste Treatment Cost	$1.66	$414,801	24.1%	
TOTAL VARIABLE COST	$6.46	$1,614,801	93.9%	
FIXED COST ELEMENTS	**Per piece**	**Annual**	**Percent**	**investment**
Equipment Cost	$0.14	$34,200	2.0%	$342,000
Auxiliary Equipment Cost	$0.03	$6,840	0.4%	$68,400
Installation Cost	$0.04	$10,260	0.6%	$102,600
Maintenance Cost	$0.01	$2,052	0.1%	
Fixed Overhead	$0.06	$15,082	0.9%	
Cost of Capital	$0.15	$37,021	2.2%	
TOTAL FIXED COST	$0.42	$105,455	6.1%	
TOTAL COST	$6.88	$1,720,256	100.0%	

ADDITIONAL INFORMATION

peration Throughput (incl rework)	253,807	parts/yr
Dry & Cure Time	2	min
Length of Drying Oven	57	ft
Number of Direct Laborers	0	/stn. (prev op)
Electric Energy Consumption	0	kW
Gas Energy Consumption	50	MBtu/hr
VOCs Generated	2.750	lb/pc
Utilization for One Station	0.1	
Actual Utilization	1.0	
Number of Parallel Stn.	1	
Equip. Investment/Station	$342,000	
Equip. Principal/Interest	$58,880	
Aux. Principal/Interest	$11,776	
Inst. Principal/Interest	$17,664	

Press Alt-G To Find Outputs ========== ========== ======= ===========

| CLEARCOAT APPLICATION COST CALCULATIONS
| Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$56.06	$14,015,863	67.6%	
Labor Cost	$0.96	$240,000	1.2%	
Energy Cost	$0.00	$0	0.0%	
Variable Overhead Cost	$0.00	$0	0.0%	
Waste Treatment Cost	$1.22	$304,569	1.5%	
TOTAL VARIABLE COST	$58.24	$14,560,431	70.2%	
FIXED COST ELEMENTS	**Per piece**	**Annual**	**Percent**	**investment**
Equipment Cost	$8.00	$2,000,000	9.6%	$20,000,000
Auxiliary Equipment Cost	$1.60	$400,000	1.9%	$4,000,000
Installation Cost	$2.40	$600,000	2.9%	$6,000,000
Maintenance Cost	$0.48	$120,000	0.6%	
Fixed Overhead	$3.53	$882,000	4.3%	
Cost of Capital	$8.66	$2,164,954	10.4%	
TOTAL FIXED COST	$24.67	$6,166,954	29.8%	
TOTAL COST	$82.91	$20,727,386	100.0%	

ADDITIONAL INFORMATION

peration Throughput (incl rejects)	253,807	parts/yr	TREQUIRE
Paint Consumption	0.500	gal/pc	
Paint Price as Applied	$110.45	/gal	
Number of Direct Laborers	2	/stn.	
Energy Consumption	0	kW (next op)	
Cycle Time	2.0	min	
Sludge Generated	0.150	gal/pc	
Utilization for One Station	0.1		
Actual Utilization	1.0		
Number of Parallel Stn.	1		
Equip. Investment/Station	$20,000,000		
Equip. Principal/Interest	$3,443,303		
Aux. Principal/Interest	$688,661		
Inst. Principal/Interest	$1,032,991		

Press Alt-G To Find Outputs

| CLEARCOAT DRYING & CURING COST CALCULATIONS

| Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$0.00	$0	0.0%	
Labor Cost	$0.00	$0	0.0%	
Energy Cost	$4.80	$1,200,000	38.5%	
Variable Overhead	$0.00	$0	0.0%	
Waste Treatment Cost	$1.35	$336,366	10.8%	
TOTAL VARIABLE COST	$6.15	$1,536,366	49.3%	
FIXED COST ELEMENTS	**Per piece**	**Annual**	**Percent**	**investment**
Equipment Cost	$2.05	$513,000	16.5%	$5,130,000
Auxiliary Equipment Cost	$0.41	$102,600	3.3%	$1,026,000
Installation Cost	$0.62	$153,900	4.9%	$1,539,000
Maintenance Cost	$0.12	$30,780	1.0%	
Fixed Overhead	$0.90	$226,233	7.3%	
Cost of Capital	$2.22	$555,311	17.8%	
TOTAL FIXED COST	$6.33	$1,581,824	50.7%	
TOTAL COST	$12.47	$3,118,189	100.0%	

ADDITIONAL INFORMATION

peration Throughput (incl rework)	282,995	parts/yr
Dry & Cure Time	30	min
Length of Drying Oven	855	ft
Number of Direct Laborers	0	/stn. (prev op)
Electric Energy Consumption	0	kW
Gas Energy Consumption	50	MBtu/hr
VOCs Generated	2.000	lb/pc
Utilization for One Station	0.1	
Actual Utilization	1.0	
Number of Parallel Stn.	1	
Equip. Investment/Station	$5,130,000	
Equip. Principal/Interest	$883,207	
Aux. Principal/Interest	$176,641	
Inst. Principal/Interest	$264,962	

Press Alt-G To Find Outputs

| CLEARCOAT INSPECTION & REWORK COST CALCULATIONS
| Materials Systems Laboratory, MIT

VARIABLE COST ELEMENTS	Per piece	Annual	Percent	
Material Cost	$6.45	$1,611,824	49.2%	
Labor Cost	$4.80	$1,200,000	36.6%	
Energy Cost	$0.00	$0	0.0%	
Variable Overhead	$0.00	$0	0.0%	
Waste Treatment Cost	$0.00	$0	0.0%	
TOTAL VARIABLE COST	$11.25	$2,811,824	85.9%	
FIXED COST ELEMENTS	Per piece	Annual	Percent	investment
Equipment Cost	$0.60	$150,000	4.8%	$1,500,000
Auxiliary Equipment Cost	$0.12	$30,000	0.9%	$300,000
Installation Cost	$0.18	$45,000	1.4%	$450,000
Maintenance Cost	$0.04	$9,000	0.3%	
Fixed Overhead	$0.26	$66,150	2.0%	
Cost of Capital	$0.65	$162,372	5.0%	
TOTAL FIXED COST	$1.85	$462,522	14.4%	
TOTAL COST	$13.10	$3,274,346	100.2%	

ADDITIONAL INFORMATION

Paint Technology:	SOLVENT	
Touch-up Paint Consumption	0.500	gal/pc reworked
Touch-up Paint Price as Applied	$110.45	/gal
Number of Direct Laborers	10	/stn.
Energy Consumption	0	kW
Utilization for One Station	0.0	
Actual Utilization	1.0	
Number of Parallel Stn.	1	
Equip. Investment/Station	$1,500,000	
Equip. Principal/Interest	$258,248	
Aux. Principal/Interest	$51,650	
Inst. Principal/Interest	$77,474	

Sludge Generated	0.150	gal/pc	
Scrapped Pieces	3,807	parts/yr	TSCRAP
Throughput (inc rework & reject)	282,995	parts/yr	TTHRU
Number of Reworked Cycles	29,188	parts/yr	TREWORK
Scrap Ratio	0.015		
Rework Ratio	0.117		
Operation Output	250,000	parts/yr	

Press Alt-G To Find Outputs

AUTOMOTIVE PAINT COST MODEL SUMMARY

Materials Systems Laboratory, MIT

VARIABLE COSTS	Per piece	Annual	Percent	
Material Cost	$149.46	$37,365,442	45.3%	
Labor Cost	$35.04	$8,760,000	10.6%	
Energy Cost	$20.22	$5,056,000	6.1%	
Variable Overhead	$0.00	$0	0.0%	
Waste Treatment Cost	$9.94	$2,483,988	3.0%	
Cost of Lost Substrates	$4.57	$1,142,132	1.4%	
TOTAL VARIABLE COST	$219.23	$54,807,562	66.5%	
EQUIPMENT COSTS	Per piece	Annual	Percent	investment
Primary Equipment Cost	$34.84	$8,709,114	10.6%	$87,091,140
Auxiliary Equipment Cost	$6.97	$1,741,823	2.1%	$17,418,228
Installation Cost	$10.45	$2,612,734	3.2%	$26,127,342
Maintenance Cost	$2.09	$522,547	0.6%	
Fixed Overhead	$15.36	$3,840,719	4.7%	
Cost of Capital	$37.71	$9,427,416	11.4%	
Building Cost	$3.00	$750,000	0.9%	$15,000,000
TOTAL FIXED COST	$110.42	$27,604,353	33.5%	$145,636,710
TOTAL COST	$329.65	82,411,915	100.0%	

Costs per Car Associated with each Operation

	Variable	Fixed	Total	
Pretreatment	$2.02	$6.61	$8.63	2.6%
Electrocoat	$23.53	$31.00	$54.52	16.5%
Sealer	$23.46	$3.70	$27.16	8.2%
Primer-Surfacer	$29.86	$8.18	$38.04	11.5%
Basecoat/Clearcoat	$135.79	$57.93	$193.73	58.8%
Other and Building	$4.57	$3.00	$7.57	2.3%
Total	$219.23	$110.42	$329.65	100.0%

ADDITIONAL INFORMATION

Total Capital Investment	145,636,710	
Floorspace Requirement	200,000	sq ft

Electricity Consumption	131,934	kWh/yr
Natural Gas Consumption	67,863	MBtu/yr
Zinc Phosphate Consumption	167	gal/yr
Chrom. Acid Rinse Cons.	167	gal/yr
Water Consumption	11,531	gal/yr
Cleaner Consumption	180	gal/yr
Electrocoat Consumption	380,711	gal/yr
Prim-Surfacer Consumption	101,523	gal/yr
Basecoat Consumption	126,904	gal/yr
Clearcoat Consumption	141,497	gal/yr
Clean & Prime Oven Tput.	253,807	pcs/mo
Surfacer Oven Tput.	253,807	pcs/mo
Topcoat Oven Tput.	282,995	pcs/mo
Lost Substrates	3,807	pcs

VOCs Generated	lbs/year	lbs/car	rcentage
Electrocoat Dry and Cure	228,426	0.914	9.7%
Sealer Application	63,452	0.254	2.7%
Surfacer Dry and Cure	558,376	2.234	23.6%
Basecoat Dry and Cure	697,970	2.792	29.5%
Clearcoat Dry and Cure	565,990	2.264	23.9%
Cleaning/Purging Solvents	250,000	1.000	10.6%
Total	2,364,213	9.457	100.0%
Tonnes of VOCs / year	1,182		

Sludge Generated	lbs/year	lbs/car	rcentage
Electrocoat Application	380,711	1.523	21.2%
Sealer Application	258,883	1.036	14.4%
Surfacer Application	304,569	1.218	17.0%
Basecoat Application	424,492	1.698	23.7%
Clearcoat Application	424,492	1.698	23.7%
Total	1,793,147	7.173	100.0%